COMPLETE **MARS** OBSERVING GUIDE

ASTRONOMY

March 1988
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Mars: The View from Space

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The Meade 10″ Model 2120/LX3 *(left)* collects **56%** more light than an 8″ Schmidt-Cassegrain. (Meade 8″ Model 2080/LX3 shown at right for comparison.)

In October, 1987, we announced a special limited-time offer for Meade 10″ Model 2120/LX3 Schmidt-Cassegrains at the unheard of price of $1799. We felt at that time that at a price of $1799, we would be able to clear our stock of 2120/LX3's by December 31, 1987.

In fact, however, the response from serious amateur astronomers throughout the United States was so overwhelming that our entire stock was depleted within 9 days of the original announcement.

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In order to amend what was clearly a difficult situation for our customers, we are pleased to announce that **Meade 10″ Model 2120/LX3's will continue to be made available at the special price of $1799 for a limited additional time, and we pledge to manufacture as many brand-new 2120/LX3's as are required to meet the demand.**

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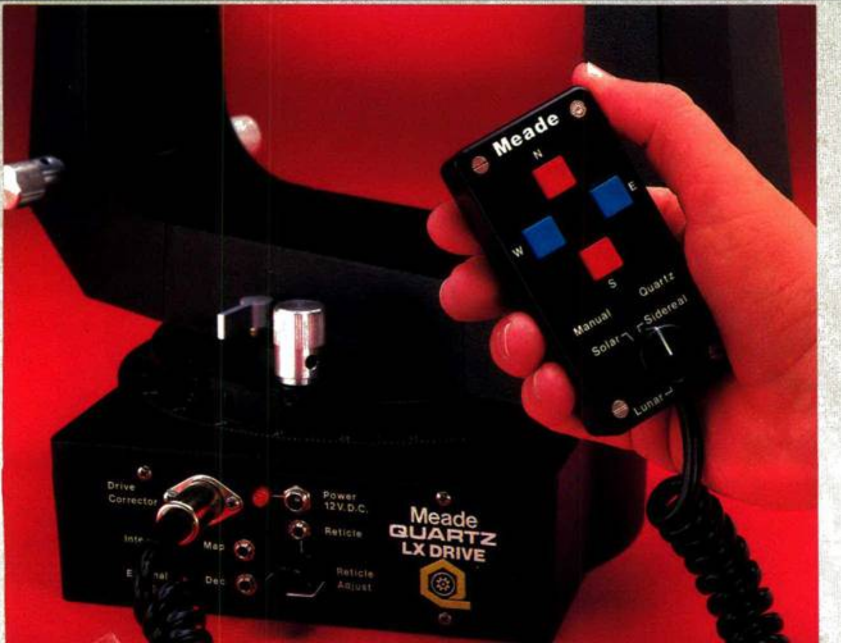
John C. Diebel, President
Meade Instruments Corporation

Each 2120/LX3 includes the #36 Electronic Drive Corrector/Hand Controller, shown plugged into the 2120/LX3 power panel.



SPECIFICATIONS:

10″ Meade Model 2120/LX3 — Includes complete 10″ Schmidt-Cassegrain optical tube assembly, with certified diffraction-limited optical system; fork mount with LX worm gear system; quartz microelectronic sidereal drive system; power panel with outlet jacks for auxiliary electronic equipment; #36 electronic drive corrector/hand controller; 25 ft. cord for operation from 115v. AC; 25 ft. cord for operation from 12v. DC auto cigarette lighter plug; setting circles on both axes; manual slow-motion controls on both axes; eyepiece-holder (1¼″ O.D.); Series 4000 Super Plössl eyepiece; #918A diagonal prism (1¼″ O.D.); 8 x 50mm polar illuminated viewfinder; multi-coated optics group; equatorial wedge with magnetic compass, latitude scale, bubble level, and micrometric azimuth control; variable-height field tripod; deluxe latitude adjuster; dust covers; foam-lined carrying case; instruction manual; lifetime warranty.

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*Through March 31, 1988, at participating Meade dealers, you can buy a Meade DS-10 or DS-16 at substantial discounts off their regular prices: only **$785** for the DS-10; **$1495** for the DS-16! Don't miss out on these super buys.*

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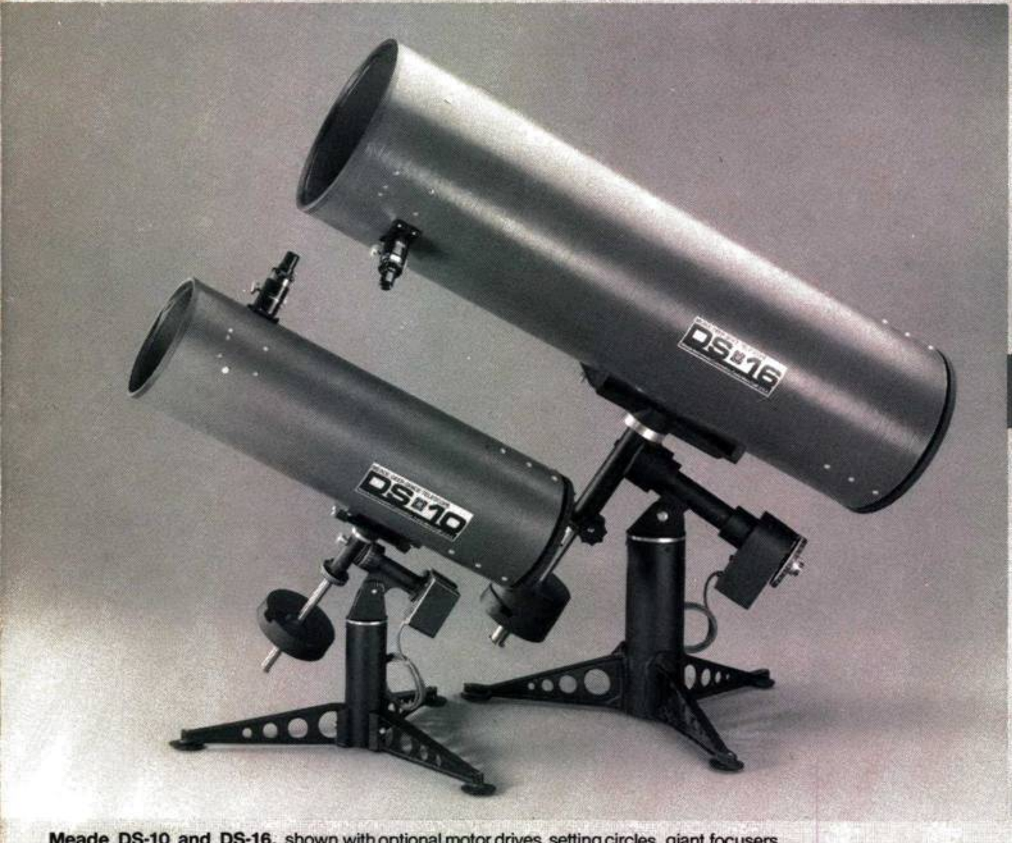

Meade DS-10 and DS-16, shown with optional motor drives, setting circles, giant focusers.

Meade DS-16 Astrophotos:
(top) Southern region of the Andromeda Galaxy (M31); *(lower)* The Horsehead Nebula. Both photos by Paul Roques.

Dealer Locations and Assistance

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Cover: The power of your imagination can turn the view of Mars through a small telescope into a trip to another world. This summer and fall, get ready for an unparalleled view of the Red Planet. The journey begins on page 58. Painting by Marilyn Flynn. These pages: Orion arches above Mount Shasta in northern California in this 5-minute time exposure by Jim Baumgardt.

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DOES BARNARD'S STAR HAVE PLANETS?

by Ken Croswell

After twenty-five years of debate the question of whether planets orbit a nearby star still has not been answered.

Six light-years from Earth in the direction of Ophiuchus a tiny red star frugally burns its fuel and casts a weak, ruddy light into space. Faint and inconspicuous, Barnard's Star is nevertheless one of the most controversial stars in the sky. Since the early 1960s Dutch-born astronomer Peter van de Kamp has maintained that tiny wobbles in the motion of this nearby star are due to the gravitational tugs of planetary companions: "We shall interpret this result as a companion of Barnard's star, which therefore appears to be a planet."

Although some astronomers believe Barnard's Star does have a planetary system and that its system may resemble our own, an increasing number of astronomers argues that the proposed planets do not exist. For instance, George Gatewood and Heinrich Eichhorn stated, "We conclude with disappointment that our observations fail to confirm the existence of a planetary companion to Barnard's Star."

The existence of planets beyond our solar system is a prerequisite for the existence of extraterrestrial intelligence. Advanced forms of life such as plants and animals can develop only on the surfaces of planets. If ours is the only solar system in the Galaxy, then ours is also the only civilization in the Galaxy.

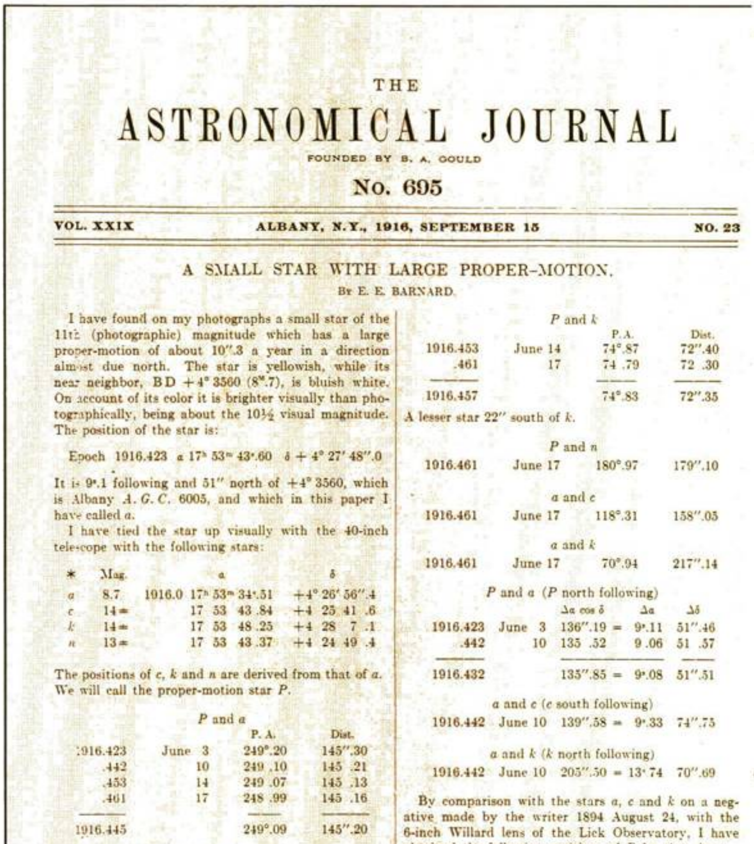
Furthermore, the discovery of other planetary systems will help us better understand our own. Which features of the solar system are common to all solar systems, and which are unique? In our solar system the four inner planets — Mercury, Venus, Earth, and Mars — are much smaller and denser than the four outer planets — Jupiter, Saturn, Uranus, and Neptune. Scientists believe this pattern is a consequence of how the planets formed and suspect that many other solar systems follow a similar pattern.

For more than a quarter of a century Barnard's Star has been the central character in the search for planetary systems beyond our own. Astronomers have taken thousands of photographs of it and written dozens of papers concerning it — a lot of attention for a star that wasn't discovered until 1916.

The Discovery of Barnard's Star

Born in the South just before the Civil War and just after his father's death, Edward Emerson Barnard confronted great poverty and adversity. As a child he received almost no formal education; instead, he was forced to work to help support his mother and himself. But, as an

"I have found on my photographs a small star of 11th magnitude which has a large proper motion."
— E. E. Barnard



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No. 695

VOL. XXIX ALBANY, N.Y., 1916, SEPTEMBER 15 NO. 23

A SMALL STAR WITH LARGE PROPER-MOTION.
By E. E. BARNARD.

I have found on my photographs a small star of the 11th (photographic) magnitude which has a large proper-motion of about 10″.3 a year in a direction almost due north. The star is yellowish, while its near neighbor, BD +4° 3560 ($8^M.7$), is bluish white. On account of its color it is brighter visually than photographically, being about the 10½ visual magnitude. The position of the star is:

Epoch 1916.423 α $17^h 53^m 43^s.60$ δ + 4° 27′ 48″.0

It is $9^s.1$ following and 51″ north of +4° 3560, which is Albany *A. G. C.* 6005, and which in this paper I have called *a*.

I have tied the star up visually with the 40-inch telescope with the following stars:

*	Mag.		α	δ
a	8.7	1916.0	$17^h 53^m 34^s.51$	+4° 26′ 56″.4
c	14=		17 53 43 .84	+4 25 41 .6
k	14=		17 53 48 .25	+4 28 7 .1
n	13=		17 53 43 .37	+4 24 49 .4

The positions of *c*, *k* and *n* are derived from that of *a*. We will call the proper-motion star *P*.

P and *a*

		P. A.	Dist.
1916.423	June 3	249°.20	145″.30
.442	10	249 .10	145 .21
.453	14	249 .07	145 .13
.461	17	248 .99	145 .16
1916.445		249°.09	145″.20

P and *c*

1916.423	June 3	178°.61	126″.34
.453	14	178 .35	126 .25
.461	17	178 .42	126 .55
1916.446		178°.46	126″.38

P and *k*

		P. A.	Dist.
1916.453	June 14	74°.87	72″.40
.461	17	74 .79	72 .30
1916.457		74°.83	72″.35

A lesser star 22″ south of *k*.

P and *n*

1916.461	June 17	180°.97	179″.10

a and *c*

1916.461	June 17	118°.31	158″.05

a and *k*

1916.461	June 17	70°.94	217″.14

P and *a* (*P* north following)

		$\Delta\alpha \cos\delta$	$\Delta\alpha$	$\Delta\delta$
1916.423	June 3	136″.19 =	$9^s.11$	51″.46
.442	10	135 .52	9 .06	51 .57
1916.432		135″.85 =	$9^s.08$	51″.51

a and *c* (*c* south following)

1916.442	June 10	139″.58 =	$9^s.33$	74″.75

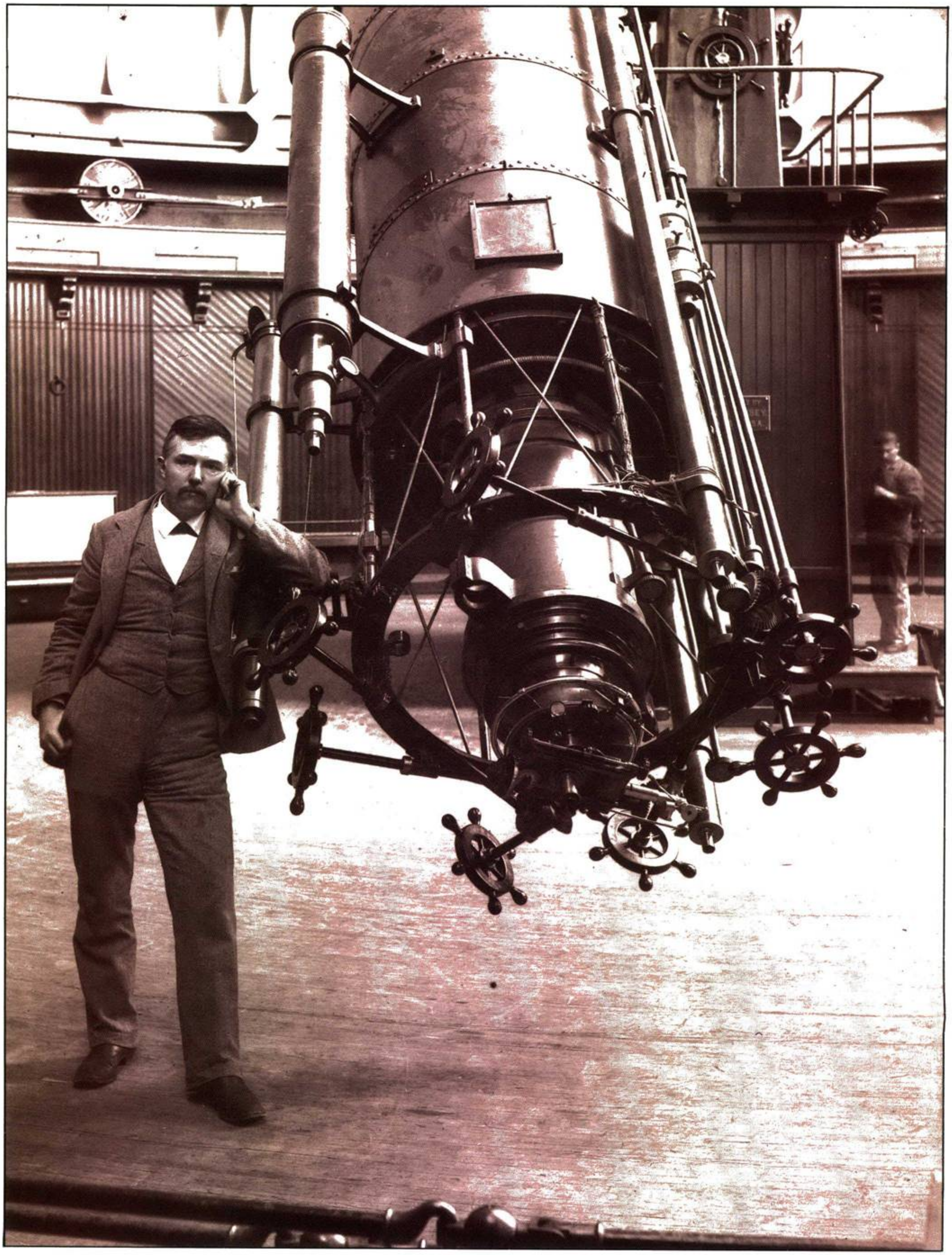
a and *k* (*k* north following)

1916.442	June 10	205″.50 =	$13^s.74$	70″.69

By comparison with the stars *a*, *c* and *k* on a negative made by the writer 1894 August 24, with the 6-inch Willard lens of the Lick Observatory, I have obtained the following positions of *P* for that date:

		α	δ
(*a*)	1894.648	$17^h 52^m 38^s.93$	+ 4° 24′ 17″.1
(*c*)		17 52 39 .30	+ 4 24 15 .4
(*k*)		17 52 39 .03	+ 4 24 17 .6
	1894.648	$17^h 52^m 39^s.09$	+ 4° 24′ 16″.7

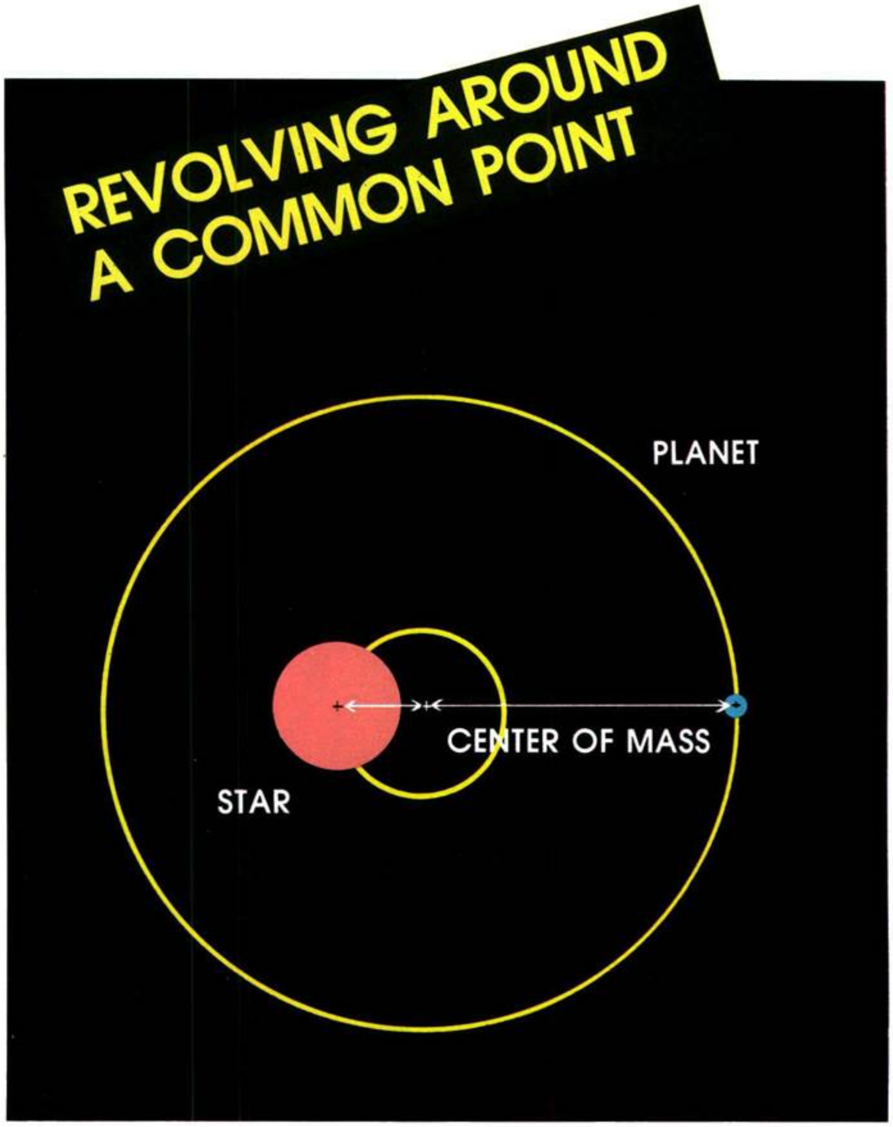
(181)



Opposite page: In the September 15, 1916, issue of the *Astronomical Journal*, E. E. Barnard announced the discovery of "a small star with large proper-motion." That star would later be known as Barnard's Star.

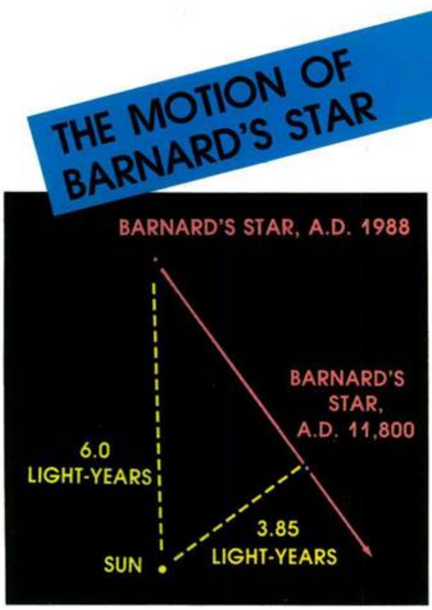
Above: E. E. Barnard initiated all the hoopla surrounding the star that bears his name when he identified the star's rapid motion across the sky. Here Barnard poses at the Lick Observatory 36-inch refractor. Lick Observatory photo.

REVOLVING AROUND A COMMON POINT


PLANET
CENTER OF MASS
STAR

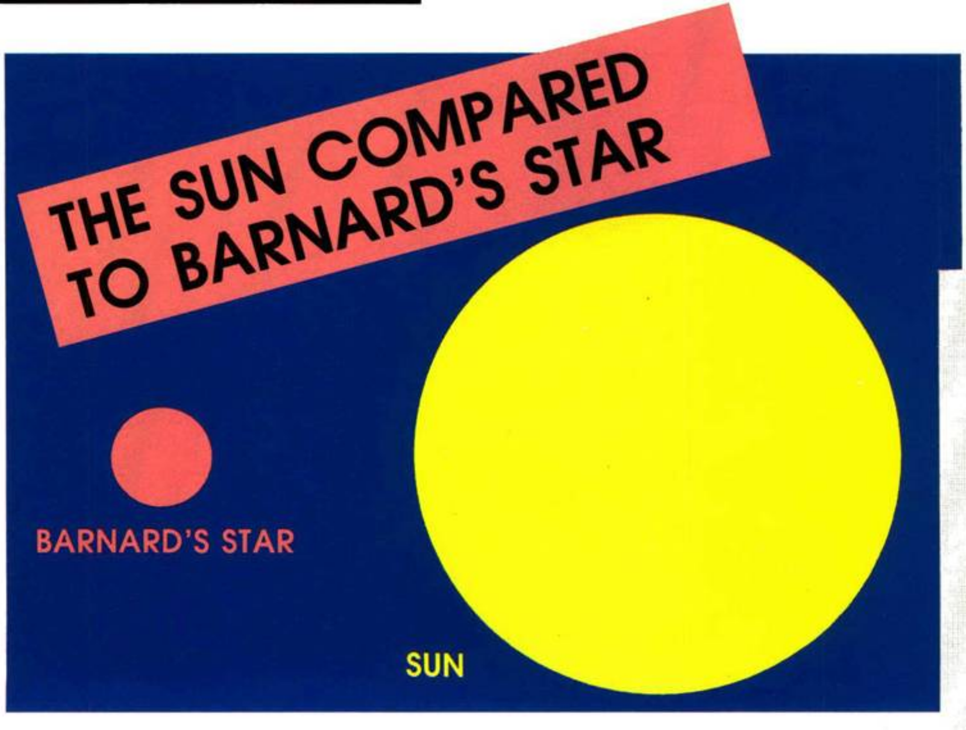
A planet does not actually orbit around the center of a star; instead, the planet and star mutually revolve around their common center of mass. For the Sun and all of its planets, this center is inside the sphere of the Sun. For a low-mass star like Barnard's Star the center of mass is farther from the star's center.

THE MOTION OF BARNARD'S STAR


BARNARD'S STAR, A.D. 1988
BARNARD'S STAR, A.D. 11,800
6.0 LIGHT-YEARS
3.85 LIGHT-YEARS
SUN

Barnard's Star moves across the sky faster than any other star. Its large proper motion is a result of both its large velocity across our line of sight and its small distance from Earth. In 10,000 years Barnard's Star will be closer than any other star but the Sun.

THE SUN COMPARED TO BARNARD'S STAR


BARNARD'S STAR
SUN

Barnard's Star is typical of most stars in the Milky Way Galaxy — it's faint, cool, red, and small. The Sun, on the other hand, is brighter, hotter, and larger than most stars.

apprentice in a photographer's studio, Barnard was unknowingly preparing himself for a future astronomical career.

Before he turned twenty, Barnard purchased a 5-inch telescope, and in 1881 he began discovering comets with it. Each new comet meant money — the philanthropist H. H. Warner awarded $200 to American comet discoverers — and Barnard discovered sixteen comets in his career. The comets brought him recognition as well as money. In 1888 he landed a job at the new Lick Observatory in California and four years later he became the first person to discover a comet photographically.

In 1892 Barnard turned the Lick 36-inch telescope toward Jupiter. Nearly three hundred years before, Galileo had discovered four large satellites orbiting the planet. Since then astronomers had found two more planets and fifteen moons in the solar system, but no one had uncovered any additional companions to Jupiter. On the night of September 9, 1892, Barnard spotted a fifth and much smaller Jovian satellite, Amalthea, the last satellite discovered without the aid of photography.

At Lick and later at Yerkes Observatory in Wisconsin Barnard photographed the Milky Way and published catalogs of the nebulae and dark clouds that line the Galaxy's plane. Many of these clouds now bear his name. At that time astronomers believed the space between the stars was free of gas and dust, but Barnard's work hinted that matter pervaded much of the interstellar medium.

In 1894 one of Barnard's photographic plates recorded a portion of the constellation Ophiuchus; in 1916 so did another. When Barnard compared the second plate with the first, he noticed a curious star that had moved substantially in the twenty-two-year interval between exposures. Barnard announced the discovery in a paper in the *Astronomical Journal*: "I have found on my photographs a small star of 11th magnitude which has a large proper motion of about 10.3 arcseconds a year in a direction almost due north." Astronomers rushed to measure the star's distance. They soon found the star lay only 6 light-years away, closer to the Sun than any other star system except the triple star Alpha Centauri. Barnard's was the second faint red star discovered in the solar neighborhood in just two years; in 1915 South African astronomer Robert Innes had discovered Proxima Centauri, the third and faintest member of the Alpha Centauri system.

	BARNARD'S STAR	SUN
Distance (light-years)	6.0	0.0
Apparent Magnitude	9.54	−26.72
Absolute Magnitude	13.22	4.85
Brightness	0.00045	1.00
Spectral Type	M5	G2
Color	Red	Yellow
Surface Temperature	3250 K	5770 K
Mass	About 0.14	1.00
Radius	About 0.20	1.00
Proper Motion	10.3 arcseconds/yr	—
Tangential Velocity*	89 km/sec	0
Radial Velocity*	−108 km/sec	0
Total Velocity*	140 km/sec	0

*Relative to the Sun

The Search for Other Planets

Once they discovered that Barnard's Star was near Earth, astronomers focused their interest on the star. In 1938 astronomers at Sproul Observatory near Philadelphia began an observing program designed to monitor the motions of nearby stars over very long periods of time to increase the accuracy of the stars' distances and to look for the effects of unseen companion objects. Barnard's Star was one of the stars in the program. Many companions turned up, both in this search and at other observatories, but most turned out to be low-mass stars. However, Peter van de Kamp discovered evidence for at least one unseen companion of Barnard's Star with very low mass — a mass more typical of a planet than a star.

These astronomers searched for companion objects by accurately measuring the changing positions of stars. These positional, or astrometric, techniques are the backbone of many planetary searches. As a star moves through space, an orbiting planet will induce small gravitational perturbations that show up in the star's motion as minute deviations from a straight-line path.

Consider Jupiter, the most massive planet in the solar system. Every twelve years Jupiter completes one orbit, but it does not really orbit the Sun. Instead it circles the center of mass of the Sun-Jupiter system. This center of mass lies between the Sun and Jupiter; it's the point where one would place a fulcrum to balance a seesaw holding the Sun on one end and Jupiter on the other. Because the Sun is a thousand times more massive than Jupiter, the center of mass lies a thousand times closer to the Sun than it does to Jupiter.

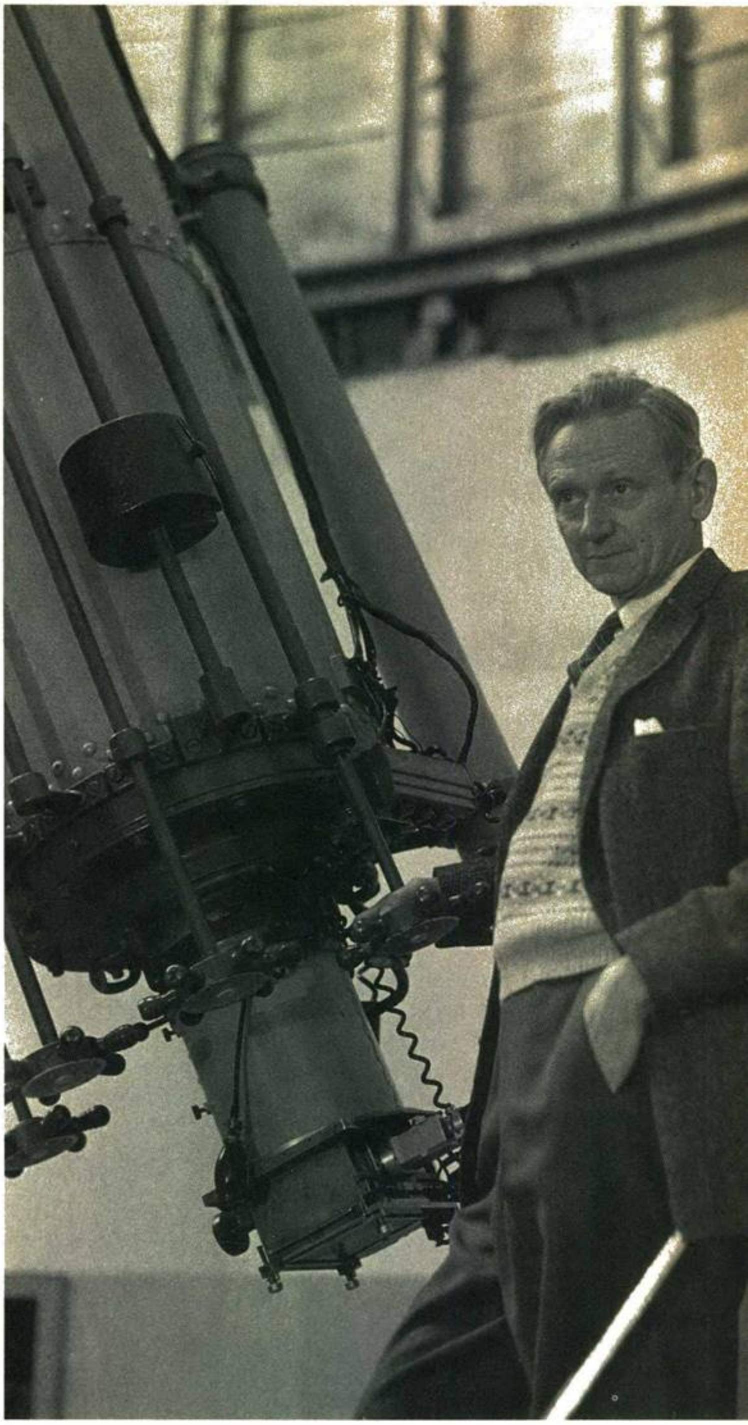
The center of mass of the two objects is therefore very close to the Sun, and every twelve years Jupiter orbits this center. But more importantly, so does the Sun. An extraterrestrial observer measuring the Sun's motion through space would detect a wobble in the Sun's path across the sky — a wobble with a period of twelve years. And if he were very careful, he'd detect a second wobble — one with a period of 29.5 years — caused by the presence of Saturn.

These wobbles are tiny, even though Jupiter and Saturn certainly aren't tiny. Small planets like Earth cause far smaller perturbations in the motion of the Sun and would probably never be detected by their gravitational effects. Therefore, the only planets we'll be able to discover with this method will be the big ones.

Another way to search for planets with this gravitational effect is precisely measuring a star's radial velocity — its motion along our line of sight — and seeing if there are any periodic variations. An orbiting planet will tug on the star, causing the star's velocity to vary in a cyclic pattern. If the planet is large enough, the velocity variations should be detectable from Earth. This method has recently shown great promise in the search for low-mass companions. Canadian astronomers Bruce Campbell, Gordon Walker, and Stephenson Yang used this technique to discover several possible planetary systems. (See "Possible Planetary Systems Discovered" by Richard Talcott, September 1987.)

Another way astronomers can search for planetary companions is by the light the planets give off. Unfortunately, planets emit no light of their own: they simply reflect the light of the star they orbit. When you see Jupiter and Saturn in the night sky, you're really seeing the sunlight these worlds are reflecting back to your eye.

"Twenty-five consecutive years of photographic observation of Barnard's Star show deviations from uniform proper motion."
— Peter van de Kamp



The major difficulty in visually detecting a planet in orbit around another star is the tremendous distances between Earth and the stars. As close as Barnard's Star is, it is still tens of thousands of times more distant than Jupiter or Saturn. The main reason you can see Jupiter with the naked eye is that it's so close. A Jupiter-sized planet in a Jupiterlike orbit around Barnard's Star would shine at 30th magnitude — dimmer by a factor of one hundred than the most powerful Earth-based telescopes can record.

To make matters worse, stars are so distant that any planetary companions they possess would appear extremely close to the star. Although Barnard's Star is dim, it nonetheless shines millions of times more brightly than any planets it has. Visually distinguishing a planet from the star's glare would therefore be extremely difficult.

One way to lessen the disparity in brightness between a star and planet is observing at infrared wavelengths. Planets must be cooler than the stars they orbit and cooler objects emit a greater percentage of their radiation in the infrared. Astronomers Ben Zuckerman of UCLA and Eric Becklin of the University of Hawaii recently discovered a possible "brown dwarf" — a type of object that falls between a star and planet — by the excess of infrared radiation in the light from its white dwarf companion. (See "Brown Dwarf Orbits Nearby Star," AstroNews, February 1988.) However, any true planet would be much cooler and therefore harder to detect than a brown dwarf, so discovering a planet with this technique will require more sensitive infrared telescopes.

Although infrared and radial velocity techniques have a great deal of potential, astronomers searching for planets still rely most heavily on astrometry. The long-term nature of many astrometric observing programs is ideal for finding planets with moderately long-period orbits.

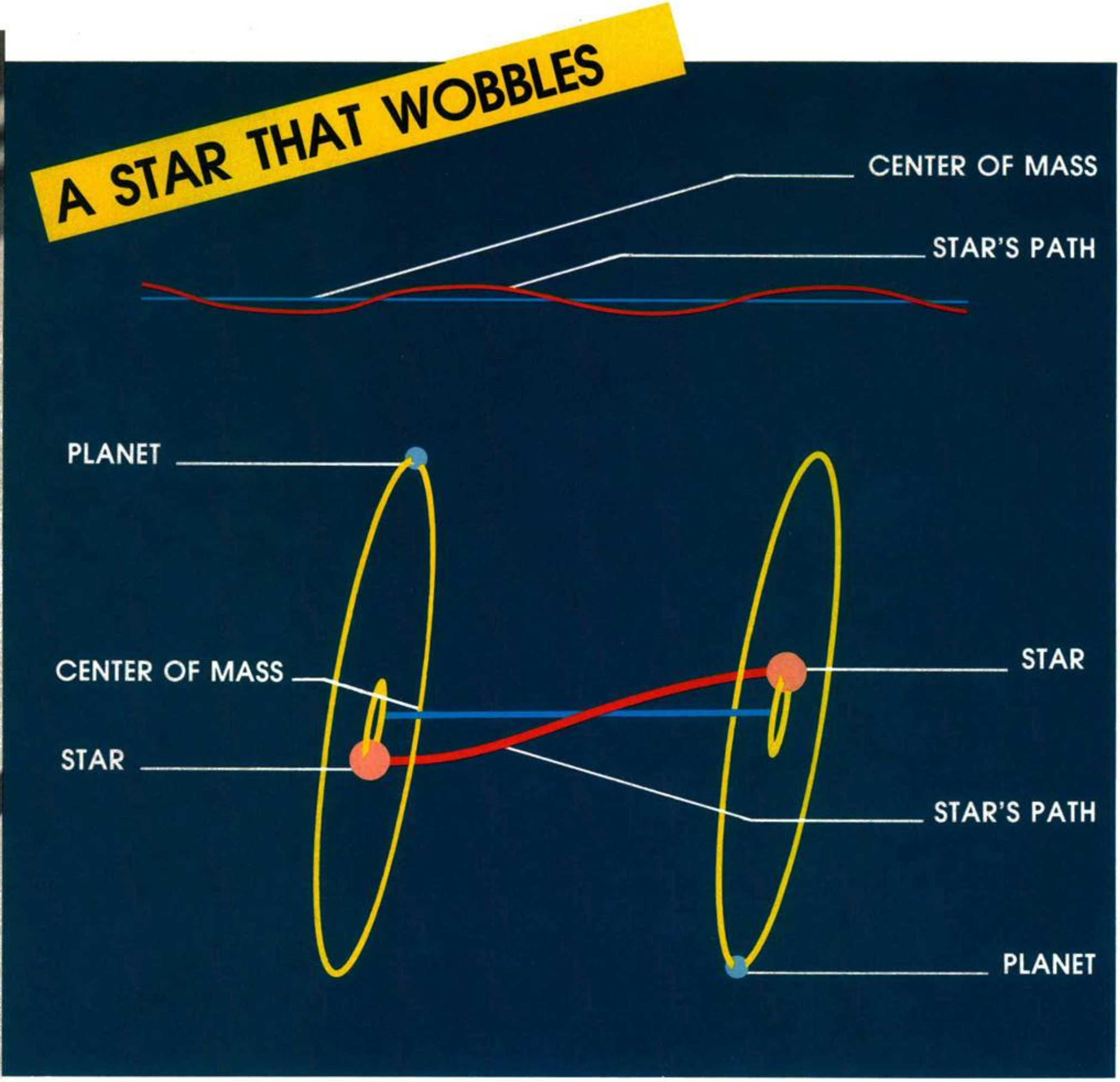
All other things being equal, astrometric observations are most likely to find planetary companions around low-mass stars that lie close to the Sun. These two attributes are the most significant in making any gravitational perturbation more obvious. Because Barnard's Star is small and nearby, it is a natural target for astronomers seeking planetary systems.

A Red Dwarf Star

A major reason any planets circling Barnard's Star should be relatively easy to find is that Barnard's Star lies just 6.0 light-years from the Sun. Suppose that a star with the same mass as Barnard's Star was located twice as far away. If both that star and Barnard's Star had a planet and both of these planets had the same mass and the same orbit around its star, then the perturbations in each star's motion would also be equal. Because Barnard's Star is only half as far away, however, the *apparent* wobble in its motion is twice as large because the *actual* perturbation subtends twice the angle.

Even though it's so close to us, Barnard's Star is invisible to the naked eye. Its apparent magnitude is a dim +9.54, so the intrinsic brightness of Barnard's Star must be very small. To measure a star's intrinsic brightness, astronomers calculate the apparent magnitude the star would have if it were at a standard distance of 10 parsecs. The resulting figure is called the absolute magnitude. Of the one hundred nearest stars the intrinsically brightest is Sirius A, which has an absolute magnitude of +1.42. The number two star is Altair with an absolute magnitude of +2.24. The Sun is also very bright: of the one hundred nearest stars it ranks seventh in luminosity and has an absolute magnitude of +4.85.

Barnard's Star, though, is 2,230 times fainter than the Sun. Its absolute magnitude is +13.22. Each month our Sun generates more light than Barnard's Star produces in a century. Barnard's Star is also cool: its surface temperature is only 3250 kelvins — much less than the Sun's surface temperature of 5770 kelvins. The low surface tem-



Left: Peter van de Kamp became director of Sproul Observatory in 1937. In 1938 the observatory began systematic observations of Barnard's Star that led to van de Kamp's discovery of perturbations in the star's motion. Photo courtesy Swarthmore College.

Above: When a planet orbits a star, the center of mass of the two objects moves in a straight line through space. Because both objects revolve around their common center of mass, the star wobbles slightly in its motion. At top is the star's wobbly path as seen by a distant observer. At bottom is an enlarged view that shows how the planet perturbs the star's motion.

perature causes Barnard's Star to glow red and the star is classified as spectral type M5. The radius of Barnard's Star is one fifth that of the Sun, and astronomers estimate the star's mass to be about 0.14 solar mass.

These characteristics place Barnard's Star firmly into the red dwarf category. Red dwarfs are cool, faint, and small. They're also very common: most stars in the Galaxy are red dwarfs. Barnard's Star is in fact a very average star, a typical representative of the Milky Way Galaxy; the Sun is not.

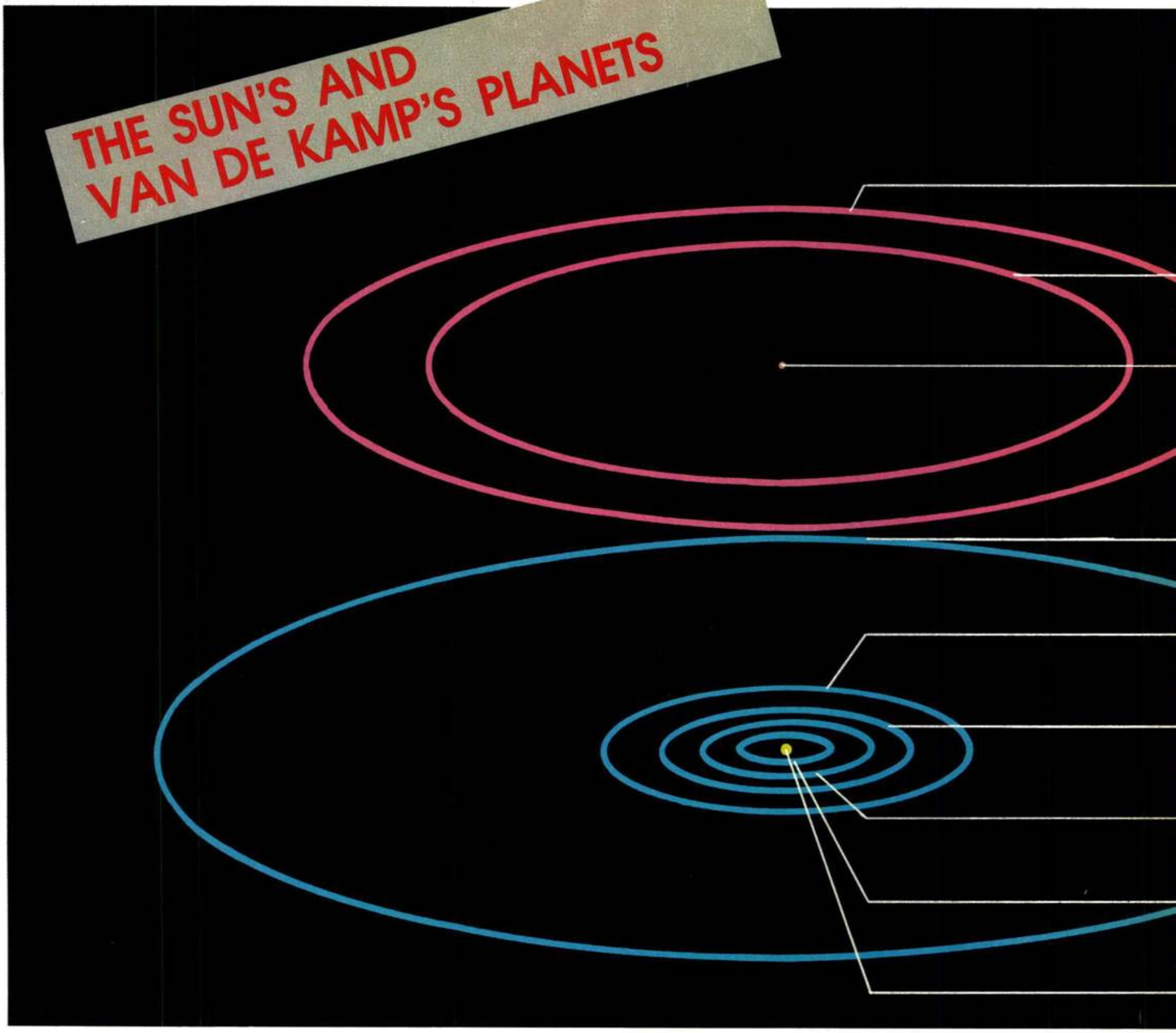
The low mass of Barnard's Star is another factor that would make any planets around the star relatively easy to detect. A star with a planetary companion wobbles around the center of mass of the two objects, and the center of mass lies farther from the star the less massive the star is. Thus, all other things being equal, a low-mass star will deviate more from a straight-line path across the sky than a high-mass star will.

Barnard's Star is rapidly approaching the Sun and will one day be the closest star to our own. Astronomers 10,000 years from now will see any wobbles that exist in the star's motion enlarged by a third.

This high rate of motion means that even though Barnard's Star is part of the local neighborhood, it hasn't always been nearby. All stars in the Galaxy orbit the Galaxy's center, and the orbit of Barnard's Star is quite different from the Sun's orbit. To compute the orbit of a star, astronomers must calculate the star's total velocity. And to do that, they must measure both the tangential velocity and the radial velocity.

The tangential velocity of a star is the star's velocity across our line of sight. To determine it, we first need to

THE SUN'S AND VAN DE KAMP'S PLANETS



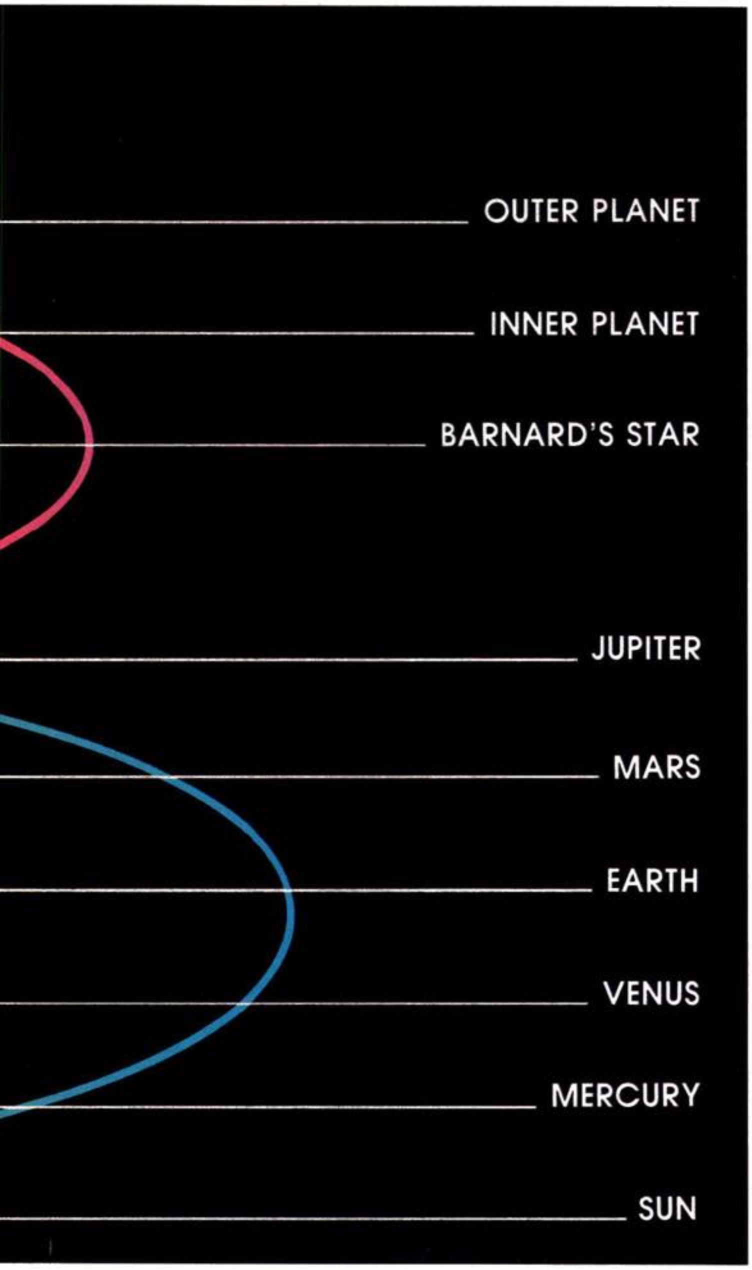
VAN DE KAMP'S PLANETS

	INNER PLANET	OUTER PLANET
Mass (Jupiter = 1)	0.7	0.5
Distance from Star (AU)	2.7	3.8
Period (Years)	12	20
Eccentricity	Close to 0	Close to 0

JUPITER AND SATURN

	JUPITER	SATURN
Mass	1.00	0.3
Distance from Sun (AU)	5.2	9.5
Period (Years)	12	29.5
Eccentricity	0.05	0.06

Van de Kamp's planets orbit Barnard's Star at a distance comparable to Mars' and Jupiter's orbit around the Sun. Because the two stars have such different masses, however, the planets would not retain their current orbits if they were switched to the other system.



measure the star's apparent movement across the sky, which is called proper motion. Edmond Halley discovered proper motion in 1718 when he noticed the positions of Sirius and Arcturus differed from those Ptolemy had recorded centuries before. Halley concluded that the stars had actually moved from the old positions to the new.

Barnard's Star has the largest proper motion of any star in the sky: 10.3 arcseconds per year. One arcsecond is one sixtieth of an arcminute, and one arcminute is one sixtieth of a degree. The Moon averages 31 arcminutes across, so Barnard's Star moves across the sky at the rate of one lunar diameter every 180 years. The star is heading almost due north: a few thousand years from now it will leave the constellation Ophiuchus and enter Hercules.

The large proper motion of Barnard's Star is a mixed blessing. On the positive side, Barnard discovered the star because of its large proper motion. In turn, the large motion implied the star was nearby and therefore any planetary companions would be comparatively easy to detect. On the negative side, the large proper motion means background stars near the position of Barnard's Star change frequently. These stars serve as references for determining the precise position of Barnard's Star, and the accuracy of this measurement is worse when the reference stars change.

Astronomers need to know more than just the proper motion of a star to deduce the star's tangential velocity; they must also know the star's distance. To see why, imagine riding in a car at fifty miles per hour. Nearby objects, such as road signs, whiz by — they have what we would call a large proper motion. Distant objects, such as far-off trees, appear to move slowly — they have a small proper motion. But all these objects are moving at the same fifty miles per hour relative to you. Clearly, distance affects proper motion.

Because astronomers can measure both the proper motion and the distance of Barnard's Star, they can calculate the tangential velocity. It's high: 89 kilometers per second. Barnard's Star has a large proper motion both because its tangential velocity is large and because its distance is small.

To get the total, three-dimensional velocity of Barnard's Star, we must also know the radial velocity. Astronomers measure this value from the spectrum of the star, which shows that Barnard's Star is approaching us at 108 kilometers per second. Combining the radial velocity with the tangential velocity reveals that Barnard's Star has a total velocity of 140 kilometers per second relative to the Sun.

This motion causes Barnard's Star to move 0.036 light-year nearer to us and brighten by 0.01 magnitude each century. The star will pass closest to us in the year 11,800, when it will be the closest star to the Sun at a distance of only 3.85 light-years and shine at apparent magnitude 8.5. The star will keep going: a million years from now it will be hundreds of light-years away; 10 million years from now it will lie thousands of light-years distant.

We can therefore paint the following portrait of Barnard's Star: It is a very normal star — cool, faint, and small — and one of our closest neighbors in space. Like most stars in the Galaxy and unlike the Sun, it is a red dwarf. And because of these characteristics Barnard's Star is a natural focus for planetary searches.

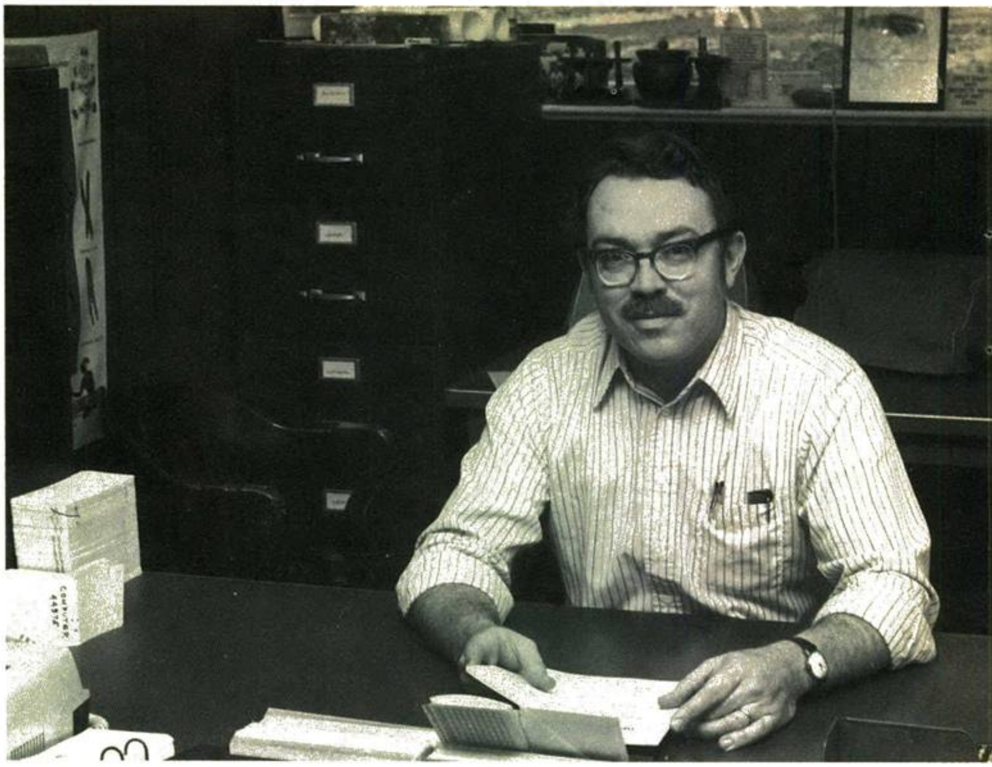
The 'Planets' of Barnard's Star

Astronomers at Sproul Observatory at Swarthmore College near Philadelphia began to systematically photograph the position of Barnard's Star fifty years ago. Since 1938 they have observed the star an average of thirty nights each year with the observatory's 24-inch refractor.

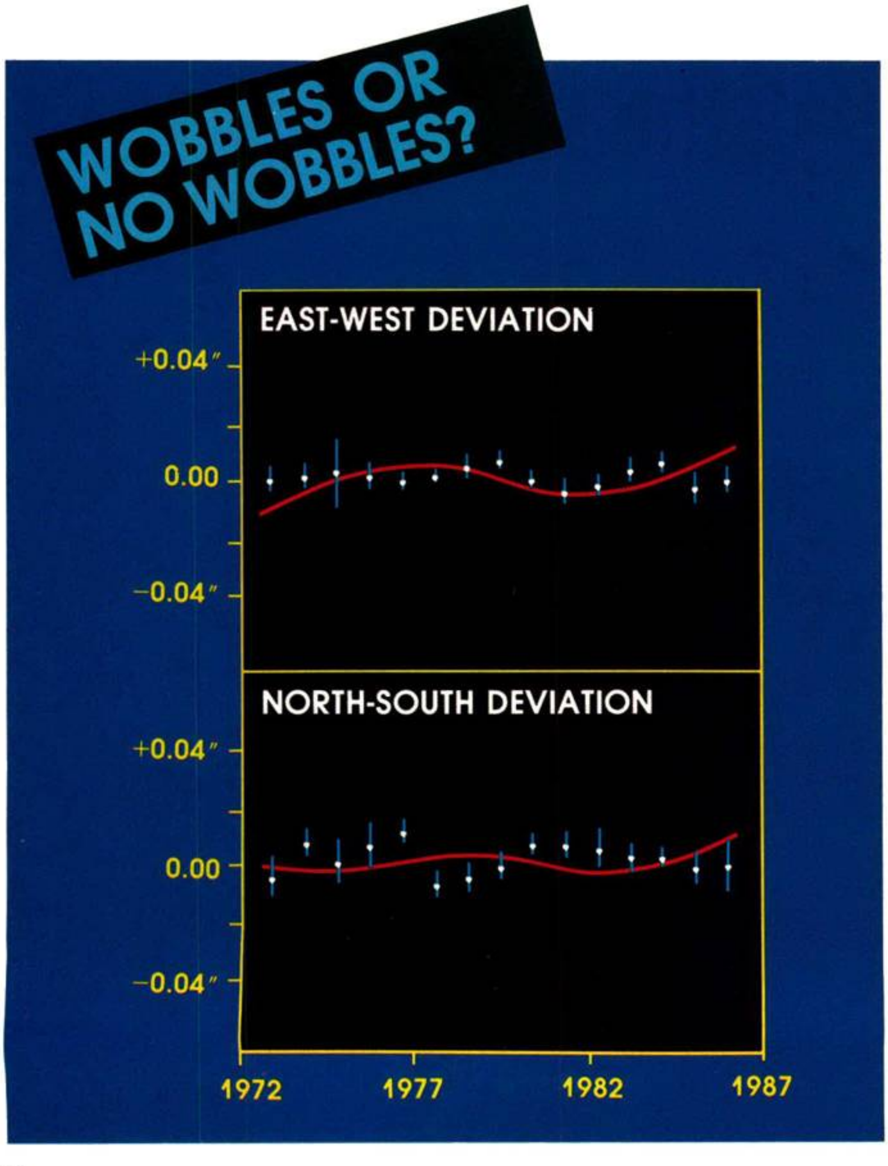
Peter van de Kamp analyzed over two thousand photographic plates taken at Sproul Observatory between 1938 and 1962. In 1962 he announced his discovery of wobbles in the proper motion of Barnard's Star, and the following year he published a full orbital analysis based on "twenty-five consecutive years of photographic observations of Barnard's star [that] show deviations from uniform proper motion." He found that the perturbation occurred primarily in the east-west direction and not in the north-south direction.

At that time van de Kamp believed the wobble could best be explained by a single large planet 1.6 times more massive than Jupiter that revolved around Barnard's Star once every 24 years in a very elongated orbit.

This planet was a strange world indeed. It was more



The most accurate astrometric data from the past fifteen years is that taken by Robert Harrington at the U.S. Naval Observatory. Harrington uses the 61-inch astrometric reflector at the USNO's Flagstaff, Arizona, station. Photo courtesy U.S. Naval Observatory.



WOBBLES OR NO WOBBLES?

A planet orbiting Barnard's Star would cause the motion of the star to deviate from a straight line. The deviations of Barnard's Star, derived from U.S. Naval Observatory data for each year, are plotted as dots for both the east-west direction (top) and the north-south direction (bottom). A straight-line path would be a horizontal line passing through 0.00; the curves show what the deviations should be if van de Kamp's model is correct.

"We have enough material by now that we ought to be able to tell whether van de Kamp's perturbation is borne out, and we don't see any signs of it at all.

— Robert Harrington

massive than the Sun's largest planet, yet it orbited a star far smaller than our own. Furthermore, the orbit was so elongated that it more closely resembled the path a typical comet would take in our solar system than the path of a typical planet. At its closest the planet came within 1.8 astronomical units (AU) of Barnard's Star — about the distance from the Sun to Mars. (One astronomical unit is the average distance from the Sun to Earth.) At its farthest the companion journeyed 7.1 AU from its star — a distance intermediate between Jupiter's distance from the Sun and Saturn's distance from the Sun.

In 1969 van de Kamp offered a different interpretation for the observed perturbation: Barnard's Star has two planetary companions. "An alternate dynamical analysis of Barnard's star's motion over the interval 1938-1968 yields two companions . . ." His subsequent analyses showed the two-planet model agreed more closely with the observations, an opinion he still holds. Van de Kamp published his last article on the planetary system of Barnard's Star in 1986 and based it on over four thousand photographic plates obtained at Sproul Observatory.

Van de Kamp's calculations revealed a planetary system that is vaguely similar to but much smaller than the Sun's system. Of the two planets, the inner one is the more massive. It has 70 percent of Jupiter's mass and revolves around Barnard's Star in a circular orbit once every twelve years. This inner world lies 2.7 AU from its parent star. The smaller planet has a mass 50 percent that of Jupiter. It circles Barnard's Star once every twenty years and lies 3.8 AU from the star.

Although the planets orbit in periods similar to those of Jupiter (12 years) and Saturn (29.5 years), both planets are much closer to Barnard's Star than Jupiter and Saturn are to the Sun. If the proposed planets were members of our solar system, they'd lie in the asteroid belt. The two planets have such long periods because Barnard's Star has a small mass and therefore exerts a weak gravitational pull on its planets, which causes the planets to move slowly.

What might van de Kamp's planets be like, and what other worlds might also orbit Barnard's Star? The two planets themselves resemble Jupiter and Saturn in size and orbit and are probably gas giants.

Speculation beyond this is dangerous: it's based on an analogy with the solar system of a very different star — the Sun. Even if Barnard's Star were just like the Sun, extrapolating from a single example would still be risky. But Barnard's Star is different from the Sun in at least two ways that would surely affect the planets of Barnard's Star: the star is much cooler than the Sun and it possesses a lower abundance of elements heavier than helium.

Because Barnard's Star is cooler than the Sun, the circumstellar disk from which its planets formed was cooler than the disk from which the Sun's planets arose. The Sun's inner planets are small and rocky because the inner part of the Sun's disk was hot. Only hardy substances like rock and iron could condense in the inner solar system. Therefore, Mercury, Venus, Earth, and Mars are mostly rock and iron. In the outer solar system where the temperature was lower, more volatile substances could condense, and the gas giants formed. Jupiter and Saturn are primarily hydrogen and helium, and Uranus and Neptune contain large quantities of water, methane, and ammonia.

A planet lying a certain distance from Barnard's Star formed in a cooler environment than did a world located the same distance from the Sun. It therefore makes sense that van de Kamp's two planets, which are probably gas giants, lie closer to Barnard's Star than Jupiter lies from the Sun. In fact, temperatures may have been so low around Barnard's Star that gas giants formed interior even to van de Kamp's inner planet.

The lower metallicity of Barnard's Star must have affected the planets as well. A star's metallicity is the star's abundance of elements heavier than hydrogen and helium. Scientists call these heavy elements metals, and the most important of these chemically are carbon, nitrogen, oxygen, and iron. Although normal stars consist primarily of hydrogen and helium, all contain some metals as well. If a star formed from an interstellar cloud rich in metals as the Sun did, the star will be metal-rich. If a star emerged from a metal-poor cloud as Barnard's Star did, the star will inherit a low metallicity.

Jupiter and Saturn are both mainly hydrogen and helium, and the largest gas giants around Barnard's Star may not be too different from Jupiter and Saturn. But Uranus and Neptune contain large amounts of rock and ice. Without metals, rock and ice can't exist; therefore, any planets farther from Barnard's Star than van de Kamp's planets might be smaller than Uranus and Neptune and in fact may not have been able to form at all. Likewise, small, dense inner planets like Earth may have had trouble forming because of the scarcity of heavy elements.

Even if these inner worlds did form, life probably has not developed on them. Barnard's Star is so faint that its planets must be quite cold. To receive as much light from Barnard's Star as Earth does from the Sun, an Earth-sized planet would have to lie a mere 0.02 AU from the star. The gravity of Barnard's Star would pull on such a planet and force one side of the planet to face the star forever, just as one side of the Moon always faces Earth. The star-facing hemisphere would become very hot, while the opposite hemisphere would be very cold. Neither would promote the development of life.

But Do the Planets Really Exist?

If Barnard's Star really has planets, its planetary system might be the closest to our own. The worlds orbiting Barnard's Star would be a likely destination of our first interstellar space probes.

But many astronomers now doubt van de Kamp's interpretation of the data and attribute the wobbles he observed to the Sproul telescope and not to the star itself. In 1973 John Hershey of Sproul Observatory published a study of twelve other stars. Using data collected at Sproul, he showed that wobbles similar to those seen in Barnard's Star appeared in them all. Hershey found that the stars exhibited a big jump in 1949, when a new cell for the 24-inch lens was installed, and a smaller break in 1957, when the objective lens was adjusted.

Clearly, more than one telescope must track Barnard's Star if definitive data is to be collected. If only one telescope records a wobble, the telescope may be at fault;

if two or three record a wobble, the star is at fault. Later in 1973 George Gatewood and Heinrich Eichhorn published an analysis of 241 plates obtained at observatories other than Sproul: 161 came from the 30-inch Thaw refractor at Allegheny Observatory in Pittsburgh, the other eighty from the 20-inch refractor at Van Vleck Observatory in Connecticut. In a 1973 paper entitled "An Unsuccessful Search for a Planetary Companion of Barnard's Star," Gatewood and Eichhorn stated that they found no perturbation in the motion of Barnard's Star.

Van de Kamp did not relent, however. He acknowledged that there had been problems with the Sproul telescope but argued that these problems could be taken into account. The data, he asserted, still demanded the presence of two unseen companions circling Barnard's Star.

At a 1983 conference on the nearby stars held at Wesleyan University, van de Kamp spoke for a few minutes on "my dear old friend, Barnard's Star." After presenting the latest data on the star, he said, "I know there are people who can't believe all this — and why not? Then why don't you start making observations for forty years, because you need about forty years to separate the two orbits [of] twelve years and twenty years. If this is real though, we have a situation similar to the Jupiter and Saturn situation, and we find this because Barnard's Star was close enough and because it pleased Barnard's Star to be a single star with planets."

German astronomer Wilhelm Gliese, an expert on nearby stars, also spoke at the conference. He summed up the dilemma by saying, "His [van de Kamp's] conclusions are still disputed and the controversy continues."

Where do things stand today? George Gatewood of Allegheny Observatory, one of the first to question van de Kamp's findings, is pessimistic. For the last four years he has been monitoring Barnard's Star with a new device called the Multichannel Astrometric Photometer. (See "The Search for Extrasolar Planets" by David Finley, December 1981.) Attached to the 30-inch Thaw refractor at Allegheny, the Multichannel Astrometric Photometer utilizes a sensitive array of photoelectric detectors to record the positions of stars and then analyzes the data by computer. The instrument is far superior to photographic plates for detecting wobbles in nearby stars.

"On the last look I had at that data," said Gatewood, "the star is moving very straight. There is no perturbation at all. This doesn't mean that there's not a planetary system around Barnard's Star. It just means that the planetary system, if there is one there, is probably not the one that Peter van de Kamp thought he saw."

Gatewood's data cover only four years, less than half the twelve-year period of van de Kamp's inner planet. For more extensive observations we must go elsewhere. "The most accurate data from the last ten or fifteen years is what Bob Harrington has," Gatewood said.

Robert Harrington is an astronomer at the United States Naval Observatory. In the 1960s the Naval Observatory built a 61-inch astrometric reflector in Flagstaff, Arizona; since 1972 Harrington has taken over four hundred photographic plates of Barnard's Star.

"We now have more than twelve years worth of data," said Harrington. "We have enough material by now that we ought to be able to tell relatively easily whether or not van de Kamp's predicted perturbation is in fact borne out, and we don't see any signs of it at all. When you plot our east-west data, it very closely follows a straight line."

"Our observations fail to confirm the existence of a planetary companion to Barnard's Star."
— George Gatewood

With the data he has now, however, Harrington can't completely eliminate van de Kamp's model. "It's not that clear-cut yet," he warned. "I can say that it's looking increasingly doubtful. I think the odds are that we would see it by now, but we can't, so I would say I would be very pessimistic . . . but I can't rule it out yet." The difficulty in being definitive, he said, is twofold. "It's partly that the period [of observations] isn't yet long enough and the predicted amplitude is not all that incredibly large."

Astronomers at Leander McCormick Observatory in Virginia are also tracking the motion of Barnard's Star. McCormick's Laurence Fredrick said, "Our measurements in [the east-west direction] are essentially flat. They show no perturbation." But like Harrington, Fredrick can't yet rule out van de Kamp's model. "We couldn't say there's no perturbation."

And what does van de Kamp think of the negative findings? "I still hold out for the two-planet interpretation. That was based on over forty years of observations." He added, "The indications are still strongest for that interpretation."

He believes the data he took is good and the deviations real. "But of course some other people felt it was a problem, because there were some other people who were looking for trouble. . . . But I was aware of the problem and I had allowed for the problem. As a matter of fact, I can leave out those years and still get the same results."

"I'm not following it up any more, because I'm retired now, so we have to leave it up to others."

One of those others, of course, is Harrington. "He's a former student of mine," said van de Kamp. "He is very trustworthy." But van de Kamp thinks Harrington doesn't yet have enough data. "If you have [periods of] twelve and twenty [years], then the two interfere with each other," and fifteen years of data is "not enough to separate the twelve years from twenty years, so give him some more time. I would say he needs at least five more years and by that time it may be settled. Give him a chance."

Gatewood, though, thinks van de Kamp's model is probably already out. Detecting planets around other stars will be quite exciting, he said, "but I think we should save our enthusiasm till we have something that's a little more demonstrable, something that we can be a little more confident in."

Van de Kamp's alleged perturbation was primarily in the east-west direction, and both Harrington and Fredrick report all is fairly quiet in that direction. Although the verdict is not yet in, most of the jurors are leaning against van de Kamp's conclusions concerning Barnard's Star.

This doesn't mean that there are no encouraging signs in the data, however. There is still another direction to consider.

"What is kind of interesting," said Harrington, "is we do see some suggestion of some activity in the north-south

direction, so we can't say for sure that nothing's going on." The movement of Barnard's Star in the north-south direction, he said, shows a big jump in 1977.

Fredrick agreed. "Our measurements in [the north-south direction] show something happened around 1977." The McCormick data therefore back up the Naval Observatory's. "We can put our stuff right on top of the Navy stuff," said Fredrick, who nonetheless cautions against reading too much into the event. "It's not clear whether this is due to a [planetary] perturbation."

Harrington is equally cautious about the observed perturbation. "All we see is a single discontinuity; we don't even see an orbit." Nevertheless, he said, "it's enough to make it still intriguing."

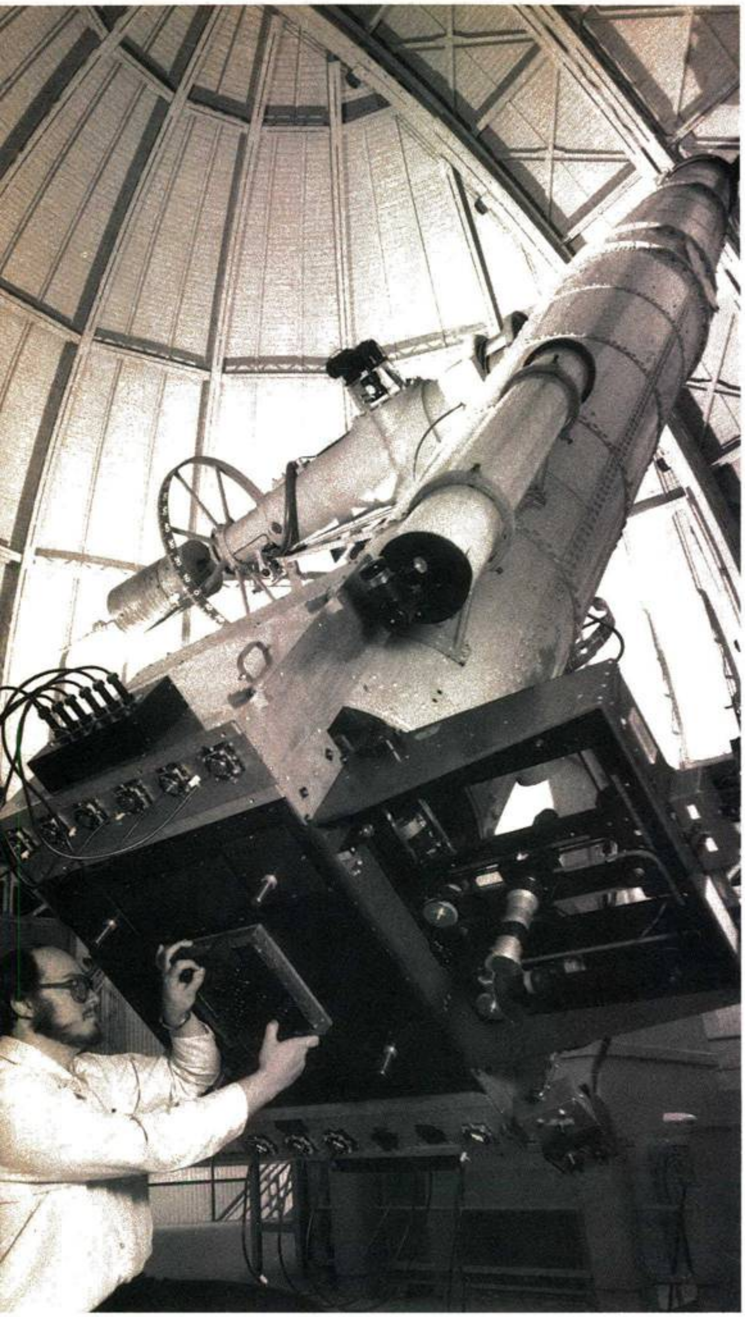
Could Barnard's Star have planets after all? Since two independent observatories saw the 1977 event, it was probably not due to problems with the telescope. If the event was caused by an orbiting planet, it will eventually repeat itself. And if that planet has a twelve-year period, the repeat performance should occur in 1989.

Future observations of Barnard's Star will take place not only from Earth but also from space. Orbiting above Earth's atmosphere and the image-distorting effects it creates, the Hubble Space Telescope and the Space Station can monitor the motion of Barnard's Star more precisely.

Even so, ground-based observers have a long head start in an area that by its very nature requires long-term observations. "Everything is usually moved to space nowadays to get a quick solution," said van de Kamp in 1983, "but even space observations cannot give quick solutions when you deal with orbits with periods of twelve years and twenty years."

"We're still going to be looking long and hard at Barnard's Star," Harrington promised.

Ken Croswell is a graduate student at Harvard University and has written for Air & Space/Smithsonian, Odyssey, Deep Sky, Space World, *and* Star Date. *His last article for ASTRONOMY was "Visit the Nearest Stars," which appeared in the January 1987 issue.*



Left: George Gatewood of Allegheny Observatory has been using the Multichannel Astrometric Photometer for the past four years to measure the position of Barnard's Star. So far he has seen no indication that the star is deviating from a straight-line path. Here University of Pittsburgh assistant astronomer James Prosser prepares the 30-inch Thaw refractor at Allegheny.

A CHRONOLOGY OF BARNARD'S STAR

1916 E. E. Barnard discovers a large proper motion star in Ophiuchus.

1938 Sproul Observatory begins systematic observations of Barnard's Star.

1962 Peter van de Kamp announces the discovery of wobbles in motion of Barnard's Star.

1963 Van de Kamp publishes orbital analysis and claims a 1.6-Jupiter mass planet circles the star.

1969 Van de Kamp advances a two-planet model to explain the motion of Barnard's Star.

1972 Robert Harrington begins regular observations of Barnard's Star at the U.S. Naval Observatory.

1973 John Hershey finds that Sproul data on twelve other stars show a similar wobble.

1973 George Gatewood and Heinrich Eichhorn analyze over two hundred plates of Barnard's Star and find no evidence of planetary companions.

1984 Gatewood begins observing Barnard's Star with the Multichannel Astrometric Photometer at Allegheny Observatory.

Our Cosmic Horizons

Part Two: The Search for Dark Matter

Adapted from an article by Virginia Trimble

Observational evidence collected over the last fifty years strongly indicates that all we can see in the form of planets, gas, stars, and galaxies amounts to only 10 percent of the entire universe. The remaining 90 percent is nonluminous and virtually undetectable, except for its gravitational effects on the visible universe. In a real sense we don't know what most of the universe is made of.

We are the stuff stars are made of. Or are we? The question, which seemed to be settled more than a century ago, is once again open.

To the ancient Greeks, it was self-evident that heavenly objects consist of a fifth element, or quintessence, fundamentally different from the familiar elements of earth, air, fire, and water.

Fashions change though. And, in 1835 when the distinguished philosopher Auguste Comte said that "never by any means will we be able to study [the] chemical composition [or] minerologic structure" of the stars, he meant the chemical composition of iron, oxygen, carbon, and silicon, like the chemicals that make up Earth. He was wrong, of course — not about the assumption but about the main point. The means had existed at least since 1815. That year the German physicist Josef von Fraunhofer recognized the great similarity between a pair of yellow absorption lines in the solar spectrum and a pair emitted by many laboratory flames. We now know these lines indicate the presence of sodium.

Science, then as now, was international. Thus by about 1862 Leon Foucault of France, Anders Angstrom of Sweden, George Stokes and William Huggins of England, Angelo Secchi of Italy, and, especially, Gustav Kirchhoff of Germany had all contributed to the idea that we can recognize individual chemical elements both on Earth and in the Sun and stars by the wavelengths of light these elements emit and absorb. Heavenly objects were made of earth-stuff and could be studied reliably via the light shining from them.

Other developments during the nineteenth century strengthened this conclusion. The tenuous gas between stars, it was discovered, emitted light from common elements. Even the first apparent counterexamples turned out to confirm the idea in the end. One example was the discovery of companion stars. The motions of Sirius and Procyon through space are not straight paths but show tiny wiggles when observed over a period of several decades. The German mathematician Friedrich Wilhelm Bessel announced in 1844 that the wiggles were the effects of invisible companion stars, moving in mutual orbits with the bright stars. No one, however, supposed these nonluminous objects might be made of "quintessence." In 1878 the American telescope maker Alvan G. Clark ground an 18-inch lens that was able to resolve the companion of Sirius as a small point of light. The companion wasn't dark after all.

Thus astronomers continued to expect that all cosmic objects radiated light and consisted of ordinary matter. This expectation was in place when the first modern evidence for nonluminous matter surfaced in 1932.

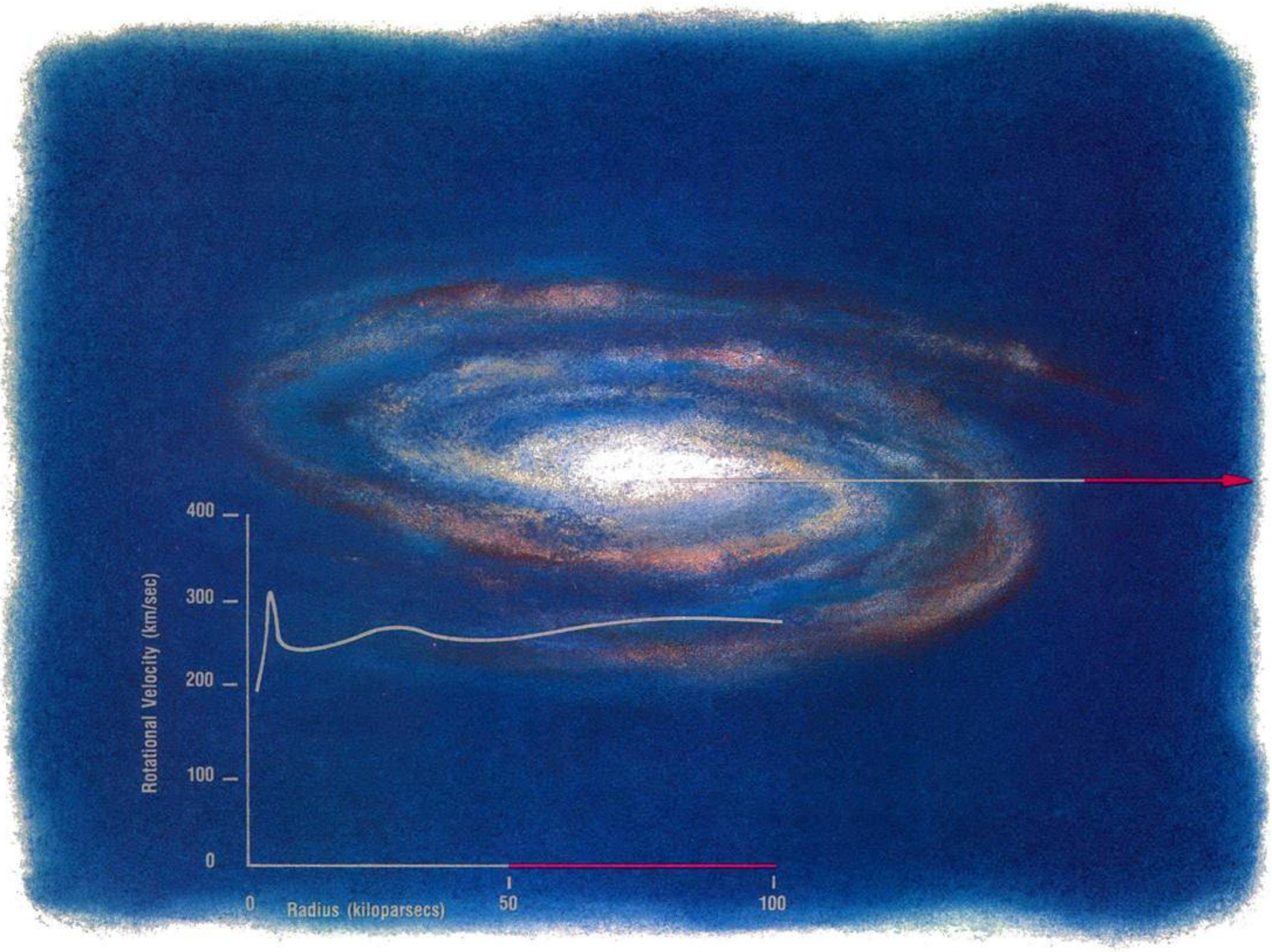
The evidence came from two rather different kinds of research. The Dutch astronomer Jan Oort had looked at the positions and motions of stars outside the disk of our own Galaxy and calculated how much mass the disk must contain to produce those motions by the force of Newtonian gravity. This amount (0.1 solar mass per cubic parsec) is called the Oort limit. Next he added up the masses of the stars visibly present in the disk. The sum came out about 50 percent smaller than the amount required to produce the motions observed outside the disk. Oort could get the correct sum only by adding in a large correction for faint, uncounted stars. Many studies later confirmed the discrepancy and ruled out many forms of gas and the large numbers of faint stars that Oort invoked to make up the extra mass. The nature of the discrepancies remains a mystery.

The other area of research was pioneered by Fritz Zwicky. A Bulgarian by birth, Zwicky came to the United States in 1925 to teach at the California Institute of Technology and work at the Mount Wilson and Palomar observatories. Zwicky measured the positions and velocities of galaxies in large clusters rather than stars in the Milky Way. This represents a scale 10,000 times or so larger than the scale Oort worked at. Still, the result was somewhat similar. The total mass required to explain the motions of the galaxies in the clusters was larger than the sum of the masses of all the cluster members, this time by a factor of something like one hundred.

Though other observers soon made similar measurements, Zwicky's discovery was not taken nearly as seriously as Oort's. Most astronomers from the 1940s through the 1960s suspected that the calculations deriving large masses from the measured motions were not appropriate to the clusters' real structure.

Zwicky died in 1974, just about the time astronomers began to appreciate the ubiquity and importance of nonluminous matter. (However, he did live to see the discovery in 1969 of the neutron star in the Crab Nebula, which he had predicted back in 1934.)

The recognition of dark matter in the universe had some aspects of what science historians call a "paradigm



Illustrations by Craig Smallish

Unseen but Not Undetected

If the greatest amount of light in a spiral galaxy indicated the location of the greatest amount of mass, most of the mass would exist in the galaxy's luminous core. Stars would obey Kepler's law of planetary orbital velocities: stars nearer the core would orbit faster than those located at greater distances from the core.

However, in recent years astronomers have discovered that stellar velocities do not decline with increasing distance from the center of a galaxy. Stars near the edge of a galaxy move at the same speed or even faster than those nearer the core.

This rotation curve of UGC 2885 was generated by radio observations of the rotation velocities of gas out to different distances from the center. The curve shows that the velocity of the gas increases out to a distance of about 100 kiloparsecs, well beyond the visible edge of the galaxy. Mass is *not* where the luminosity is. Rotation curve courtesy of Ronald J. Allen, Department of Astronomy, University of Illinois.

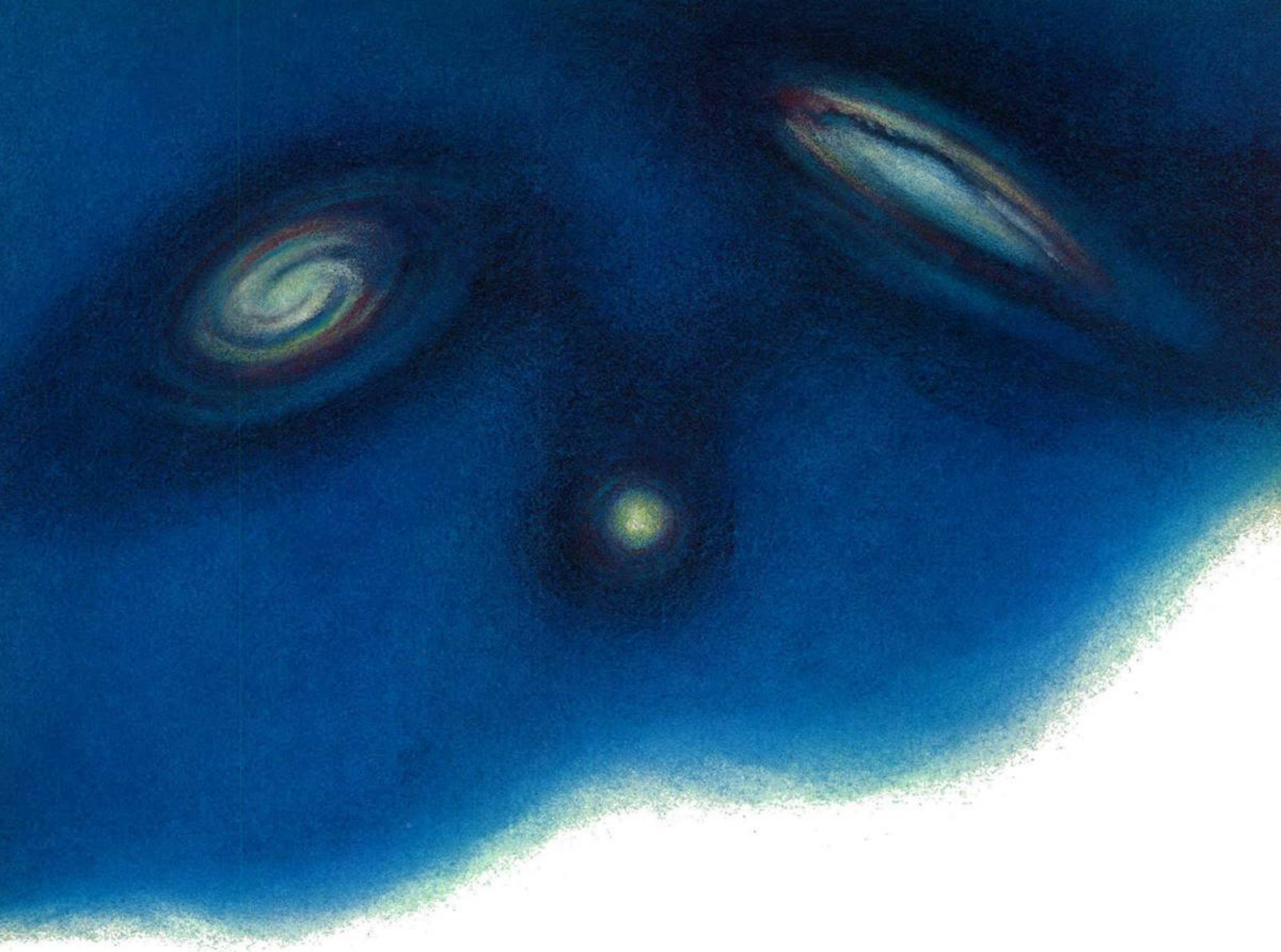
shift.'' That is, it involved not just new data but also a new way of looking at old data and problems that had been around a long time, especially questions about the formation, evolution, and structure of galaxies. The seminal event in this paradigm shift was a pair of short papers published by trios of American and Soviet astronomers. Neither presented much new data. But each had disparate bits of information, the collective import of which was that the mass associated with a typical galaxy extends out to much larger distances from the center than does the light. Thus the total mass of a galaxy depends on the distance from the center at which you are able to probe and increases linearly with that distance out to 100 kiloparsecs.

Today's evidence for dark matter is based on the same kinds of research pioneered by Oort and Zwicky, but of course there is more information in each research area. Let's look into some of these areas, beginning with the smallest scales and objects closest to us, and see what the data look like and what the data imply about the nature of the dark matter.

Dark Matter in the Milky Way

The discrepancy identified by Oort persists. The motions of nearby stars reflect the gravitational attraction of about 50 percent more mass in the galactic disk than we can find in the form of stars and gas. The inventory is closer to being complete than it was in 1932. New techniques of radio, infrared, ultraviolet, and x-ray astronomy allow us to detect gas at all temperatures and to count individual stars fainter than the Sun by a factor of 100,000 or more. Nevertheless, neither gas nor very faint stars contribute more than about 10 percent of the Oort limit.

What other nearby hidden massive objects might qualify as dark matter candidates? Brown dwarfs, perhaps. These are spheres of gas just a little too small to burn hydrogen and shine like stars. Or old, faint white dwarfs, the cores of a generation of moderately massive stars that died long before our Sun was born. Or maybe black holes, but only tiny ones with masses like planets and diame-



The Tip of the Iceberg

Dark matter makes up about 90 percent of the mass of most galaxies. Although dark matter has never been directly detected, many astronomers believe its presence explains the rotational velocities of stars in galaxies as well as the behavior of galaxies in clusters. In this illustration dark matter envelopes a cluster of galaxies. Without dark matter, the gravitational attraction of the galaxies alone could not contain the cluster.

ters of a few centimeters or enormous ones with masses up to a million times that of the Sun and diameters of a million miles. (Stellar-mass black holes or neutron stars won't do because gas falling on them would produce brighter x-ray emissions than we can see.) Or, just possibly, one of the more exotic types of objects on larger scales, such as axions, neutrinos, or cosmic strings.

Effects on Galaxy Rotation Velocities

Techniques for ferreting out dark matter in whole galaxies are many, but the general idea is to measure the velocity of gas as gas moves around the galaxy at a large distance from the galactic center, which would give us an indication of how the gas responds to the gravitational force (hence the mass) of the central galaxy.

For spirals, the definitive data come from rotation curves. These are plots of the orbital speed of gas in the disk of the galaxy as a function of distance from the center. The speeds are found from the Doppler effect — a small change in the wavelength of light we receive that is directly proportional to the speed of the gas toward or away from us. Once you know the orbital speed, V, and the distance from the center, R, the calculation is simple. To within a small factor, the mass of the galaxy inside the orbit of the gas you measured, M, is just V^2R/G, where G is Newton's constant of gravity.

Most galactic rotation curves show a constant velocity value over a wide distance range: the mass found this way typically gets bigger out to the largest radius where you can record anything. And the total often exceeds the summed masses of visible stars and gas by a factor of five to fifteen; in other words, there is more dark matter than luminous matter in galaxies. The gory details of gas and star velocities in spirals strongly suggest that most of this dark matter is not in the bright, flat disk but in the faint spherical halo.

Deducing the amount of dark matter in elliptical galaxies is a bit trickier. Most ellipticals do not have enough gas to radiate bright, easily measured spectral lines. And most of the big ones do not rotate. Thus we have to use absorption lines in the spectra of the elliptical galaxies' stars to measure the Doppler effect, and instead of plotting a tidy rotation curve with a very simple calculation to follow, all we can plot is the range of stellar velocities, from which the calculation of mass is much more

elaborate.

Still, the result is much the same for ellipticals as it is for spirals. The farther out from the center of the galaxy you look, the larger the mass you calculate, and the total is nearly always much larger than the sum of the stars you see. Confirmation of the large masses comes from the two subsets of ellipticals — those with companion galaxies or globular clusters in orbit around them (for which we can measure velocities and so masses by V^2R/G) and those with very hot gas in them. Such hot gas emits x-rays, from which we can figure out the gas temperature. The temperature determines the velocities of individual gas atoms at a given distance from the center of the galaxy and so again the mass can be calculated.

Candidates for dark matter in whole galaxies cover the same wide range as those for the Oort limit. The exotic candidates look more interesting, though, because their inclusion in galaxy formation models helps to solve old problems (remember this is one of the things a paradigm shift is supposed to do!).

One of the old problems that needs to be solved is how galaxies form. On large scales the universe is very smooth: the 2.7-kelvin microwave background radiation — the remnant of the radiation content of the Big Bang — varies less than 0.001 percent around the sky. Yet at the smaller scales of galaxies and clusters the universe is very lumpy (and a good thing or we would not be here to worry about it).

How could the lumps have grown to their present sizes, masses, and clustered arrangements from such a smooth beginning? Dark matter, especially dark matter occupying bigger volumes than visible stars in galaxies, helps account for the smoothness precisely because the dark matter is not as concentrated and lumpy as the visible matter and thus not as likely to perturb things. The exotic dark matter candidates help even more, because they do not scatter radiation very effectively.

Quite big lumps can grow in the dark material without disturbing the background. Then, later, ordinary gas flows into those lumps to produce the galaxies and stars we see. Dark matter particles behave somewhat differently depending on whether they are fast- or slow-moving when galaxies form, hence the distinction between "hot" and "cold" candidates.

Clues in the Orbits of Small Galaxy Groups

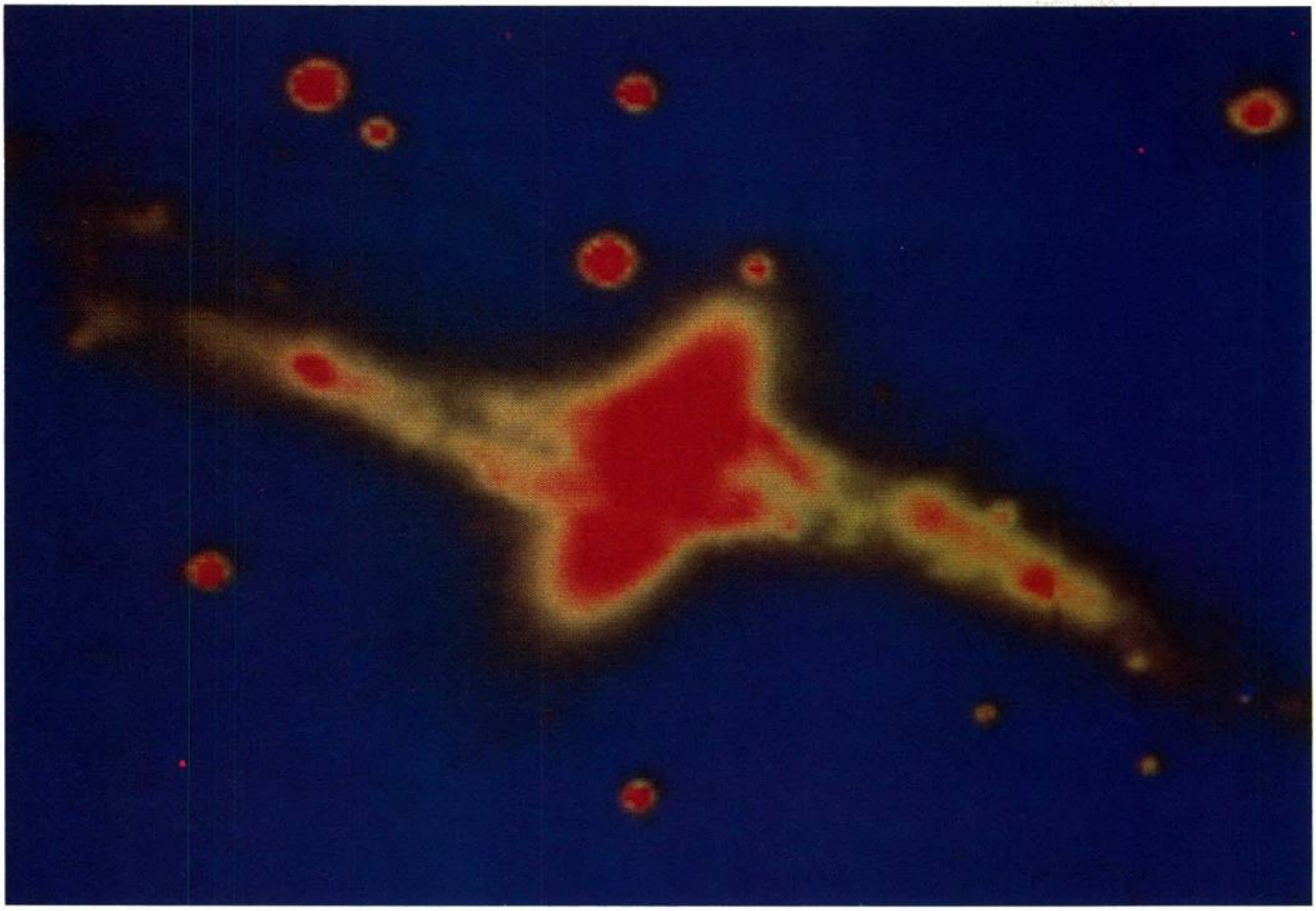
As we consider the implications of dark matter at the scale of binary galaxies and small galaxy groups — including our Local Group — both the measurements and the calculations become more difficult in practice, though they are much the same in principle. The observer records the sky positions of galaxies at this scale and calculates the velocities from the Doppler effect. The catch is that these are not exactly the distance and velocity needed. Each is a projection — one or two dimensions of the three-dimensional quantity wanted. Correction for this is possible, but the amount depends on whether you think the orbit of a pair of galaxies is like a circle; a long, skinny ellipse; or something in-between. A standard guess is that the orbit is a mixture of these (called an isotropic velocity distribution). When such an orbit is applied to binary galaxies and galaxy groups, it yields total masses exceeding the luminous masses by factors of ten to thirty.

For the Local Group we can do a different, supporting calculation. The Milky Way and Andromeda galaxies are now moving toward each other at a speed of about 100 kilometers per second. Yet they must have formed while moving apart, because the universe as a whole has been expanding for 10 billion to 20 billion years. Thus the present motion probably comes from the gravitational attraction between the two galaxies. To calculate the mass needed for this motion, we can combine the approach speed, the present separation (about 650 kiloparsecs), and the time available for the motion. Our answer is 4 to 7 $\times 10^{12}$ solar masses, like that found for many other pairs and small groups. Dark matter exceeds luminous matter by ten to thirty times on this scale. Thus, the same wide range of candidates remains possible.

Telltale Motions of Galaxy Clusters

The velocities and positions of the members of the Coma galaxy cluster, which Zwicky studied, and about a hundred other galaxy clusters have been measured and used to estimate masses. If these estimations are correct, visible clusters of galaxies represent nothing more than bright foam floating on an ocean of dark matter.

As in the binary case the values we measure are projections of the ones we want and require a correction factor. In addition, the clusters are so big that galaxies lying at vast distances from one another may not yet have had



Polar-Ring Galaxies Probe Dark Matter

How is dark matter distributed around galaxies? Polar-ring galaxies may help us answer this question. This false-color image of polar-ring galaxy NGC 4650A shows a red disk of old stars oriented perpendicularly to the nearly edge-on disk. Stars in the polar rings of these galaxies are distributed far above and below the disk, yet astronomers find that these stars orbit with nearly the same velocity as stars in the disk. This means dark matter must be distributed spherically around the galaxy rather than in a flattened disk. Photo courtesy of Brad Whitmore and Douglas McElroy, Space Telescope Science Institute, and Francois Schweizer, Carnegie Institution of Washington.

time to respond to one another's gravitational forces. This requires another correction factor, which can be obtained from a computer simulation in which many points, representing galaxies or their precursors, are plopped down in space and allowed to interact for 10 billion to 20 billion years.

With luck, this period can be compressed into a few hours of computer time. The results reveal that the total calculated masses of the clusters exceed the masses of the luminous regions by still larger factors of one hundred to as much as three hundred times. Even if you suppose that the mass properly belonging to a single galaxy can be deduced by its rotation curve (which already indicates 80 to 90 percent dark matter), the clusters are still too massive by another factor of ten or so and must average about 99 percent dark matter.

At the Largest Scale

Some scientists are pretty sure the total mass everywhere in the universe must be about one thousand times the luminous part. The corresponding density is only one atom per bathtub-volume — a value known as the critical density of the universe — but it is just enough for the collective gravitational force to reach a stand-off with the present universal expansion, so the expansion continues for an arbitrarily long time but eventually slows to an arbitrarily small speed. A popular picture of the very early universe, called inflation (see "Has Cosmology Become Metaphysical?" by Tony Rothman and George Ellis, February 1987), requires the average density to have very nearly this critical value.

Dark Matter's Point of Origin

If we are to develop an acceptable theory about what dark matter is and how much of it exists in the universe at these different scales, we must take the exotic candidates still more seriously. When we examine nuclear reactions that occurred 10 billion to 20 billion years ago (after inflation but before galaxy formation) when the universe was still hot and dense, we find that ordinary chemical elements do not exist. We do find a soup of separate protons, neutrons, electrons, and radiation (not to mention positrons, neutrinos, and other oddities that need not concern us here). As the universe expands and cools from the hot state, the individual particles interact with hydrogen nuclei to form hydrogen's heavy variation deuterium, two kinds of helium, and just a bit of the light metal lithium.

How much of each element is produced depends on how many protons and such were there to interact in each volume of space. The higher the density — the more particles there are — the easier it is for the particles to collide and react with one another. Higher densities tend to make more helium at the expense of hydrogen and, especially, deuterium. If we knew just how much helium, deuterium, and so on was made in the early universe, we would know the density of the proton-neutron soup and thus the average density of the universe in the form of ordinary matter.

Unfortunately, no pure samples of early universe gas remain to be measured. It has all been synthesized into other elements by additional nuclear reactions in stars (another thing to be grateful for, because we are made of carbon, nitrogen, and other nuclear by-products!). But looking at the most primordial stuff we can find and subtracting the stellar contributions, we find rather more deuterium (about two atoms for every 100,000 atoms of normal hydrogen) and less helium (somewhat less than 25 percent) than you might expect if you assumed these abundances solely reflected the luminous content.

How Much Dark Matter Is Needed?

The amount of normal matter needed in the early universe to make the element abundances come out right is between 50 and 150 times the amount we see today as luminous mass. Apparently, then, some of the dark matter must be ordinary stuff, "hiding" in the form of brown dwarfs, white dwarfs, or whatever. The clusters and superclusters of galaxies are on the ragged edge of this normal matter limit and need a dark matter-to-luminosity ratio of one hundred to three hundred. And it would be very difficult indeed to accommodate a critical density — where the dark matter-to-luminosity ratio equaled one thousand — in the kind of matter that participated in nuclear reactions in the early universe.

There may be a way around the dark matter limit if we assume the universe was already quite lumpy (especially in its ratio of protons to neutrons) when the nuclear reactions took place. Several groups of astronomers, including Craig Hogan, James Applegate, and Philip Scherrer in the United States and Martin Rees in England, are currently exploring this idea, called inhomogeneous nucleosynthesis. But unless this process proves effective in encouraging production of deuterium and suppressing that of helium and lithium, we will still be forced to say we cannot have a critical density of ordinary matter. Astronomers who think the average density of the universe really is the critical value must look long and hard at the alternatives to ordinary matter.

Exotic Candidates

What can we say about the exotic candidates? Remarkably little from an experimental or observational point of view. Several different kinds are predicted by different branches of modern theoretical physics. Their names are many and varied. The popular collective nouns are "inos" (because many of the candidates are related to known particles in a way that tempts one to invent words like photino from photon and gravitino from graviton) and WIMPs, for weakly interacting massive particles. The "weakly interacting" part is what makes these particles useful for dark matter. Nuclear reactions among protons and neutrons carry on almost as if WIMPs weren't there, and even the smooth background radiation is largely blind to them. The "weakly interacting" part also makes these particles difficult to study. Most of the time WIMPs will go right through the Earth and the Sun, not to mention a laboratory detector.

Experiments at Stanford and London have just possibly seen one magnetic monopole, the magnetic equivalent of single electrically charged particles. And groups in the Union of Soviet Socialist Republics and the United States have reported evidence that neutrinos have a nonzero rest mass (the existence of neutrinos is not at issue, only the question of whether neutrinos are truly massless like photons or merely tiny). Other rather simple experiments have not reproduced these results, and neither the monopoles nor the massive neutrinos are widely accepted at the moment. A dozen or more experiments are in progress or planned.

Meanwhile we can set some additional dark matter limits from the fact that WIMPs in large concentrations in stellar cores or galactic haloes interact enough to produce light, hasten nuclear reactions, and so forth. These effects are probably not too large, or we would already know about them. Thus, in different ways, for instance, the number of gamma rays radiated from the galactic center and the number of stars evolved in globular clusters rule out certain combinations of WIMP masses and interaction rates, none of these limits is currently tight enough to eliminate even one of the dark matter candidates.

Well then, is the universe really made of earth-stuff or not? Despite Auguste Comte, we know with confidence that the luminous stars, gas, and galaxies consist of standard chemical elements — hydrogen, helium, and all the rest up at least to uranium — in standard proportions. But the universe as a whole is not very luminous. Somewhere between 90 and 99.9 percent of its mass does not radiate, and so the universe's chemical composition and mineralogic structure cannot be studied directly.

If the dark matter outweighs the luminous matter by a factor of only ten to one hundred, then dark matter may well be normal material, hiding in brown or white dwarfs or black holes. We cannot prove that it is, but we have no reason to conclude that it isn't (apart from the difficulty of understanding galaxy formation). If, on the other hand, the inflationary scenario or some other argument for a critical density proves correct, then WIMPs or inos become serious contenders for the dominant constituent of the universe. Deuterium and helium come out right, and galaxy formation looks more straightforward (though the problems have not all been solved even by models that invoke hot or cold dark matter or a mixture of the two).

How am I betting? At least fifty-fifty on protons and neutrons all the way. The remaining probability is distributed very thinly (though quite uniformly) among the many other exotic dark candidates. Clearly one definitive laboratory experiment, recording the presence of axions, higgsinos, or whatever, could change the odds drastically, though the chance of one experiment being much more definitive than the current hints of monopoles and massive neutrinos is rather small.

We are made of star-stuff, in a narrow sense of the word, but whether or not most of the universe is made of star-, earth-, and people-stuff is once again an open question.

Next month Stephen A. Gregory explains how the distribution of visible matter and voids shapes the large-scale structure of the universe.

Virginia Trimble is a professor of physics at the University of California at Irvine and a visiting professor of astronomy at the University of Maryland.

ASTRONOMY Forum

The Real Lives of Ten Top Astrophotographers

What do a priest in California, a professor of biology in Africa, a store manager in Canada, and a securities analyst in New York have in common? They, along with six others, are astrophotographers. What drives these people to painstakingly record images of planets, galaxies, and clusters and send them to be published? What do these photographers of the sky have in common? How do they weave a disruptive, nighttime hobby like astrophotography into their lives?

For all of these backyard astrophotographers, collecting images of the sky on film is a relaxing way to escape from the pressures of life and enjoy the beauty of the universe. The enjoyment they get from their hobby outweighs the effort they must put forth to make photographs of celestial objects. But, while all these astrophotographers are devoted to their hobby, each of them has a unique angle on that hobby.

This year professor Jean Dragesco is celebrating his golden anniversary as an observer. A research scientist studying microorganisms in Butare, Rwanda, Dragesco developed his love for the sky in 1938. Now sixty-seven, Dragesco has produced thousands of high-resolution photographs of the planets, especially Mars.

Dragesco observes and photographs every night the weather allows. "High-resolution photography can be easy with the benefit of good seeing," Dragesco said. "But it is impossible with bad seeing. In Butare the seeing is abominable and there is too much light pollution. I cannot do any high-resolution work. Even deep-sky photography is difficult as there are few totally cloudless nights."

> **"The very good amateur astrophotographers are as good as the best professionals."**
>
> — *Jean Dragesco*

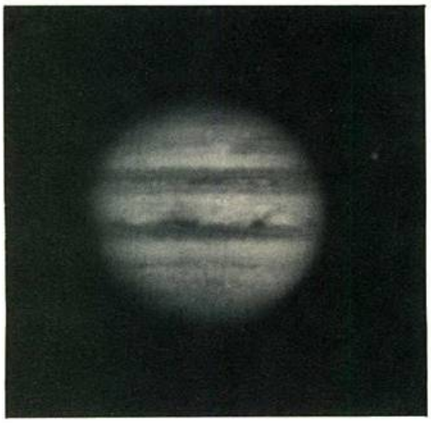
Besides taking astronomical photographs, Dragesco has produced many photographs of wildlife, some of which have appeared in *National Geographic*, and four of his children are actively interested in this aspect of recording nature. But none of Dragesco's six children appears likely to follow in his father's footsteps as an astronomical photographer.

Why astrophotography? "Astronomy is the most important part of my life," Dragesco said. Photographing the sky with great care is obviously something Dragesco and his colleagues can be proud of. "The very good amateur astrophotographers are as good as the best professionals," said Dragesco. "We must obtain the best image possible with the aperture we have. We must never be satisfied."

Forty-year-old Jack Marling is another professional scientist turned astrophotographer. After receiving his Ph.D., Marling worked for many years in applied physics and optics at the Lawrence Livermore Laboratory in Livermore, California. Ten years ago Marling bought a telescope and began taking photographs of sky events. Having been interested in photography and involved with optics professionally, Marling started improving various attachments and accessories he used for his astrophotography.

Marling's inventions led him to leave Lawrence Livermore in 1979 and form a business for astrophotographers called Lumicon. He was instrumental

> **"Capturing a lovely object on film and sharing celestial beauty with others is what drives me."**
>
> — *Jack Marling*



Jupiter; photo by Jean Dragesco

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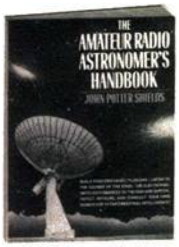
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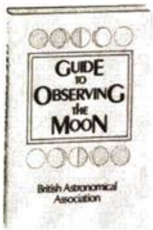
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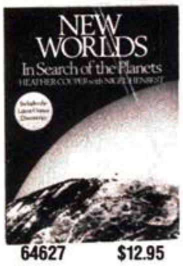
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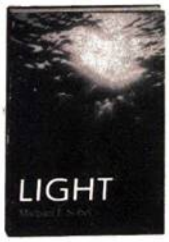

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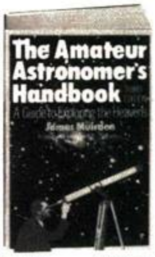
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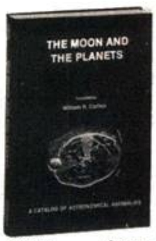
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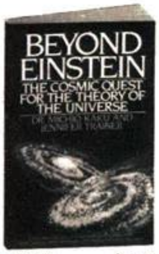
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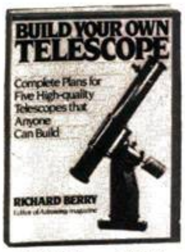
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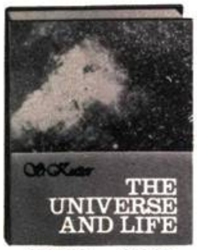
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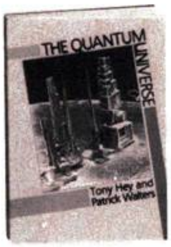
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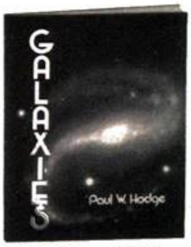
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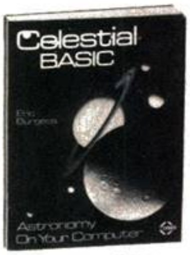
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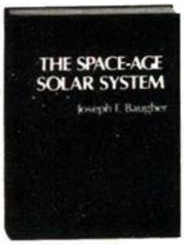
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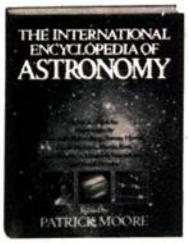
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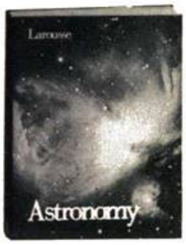
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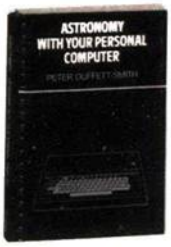
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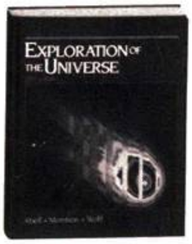
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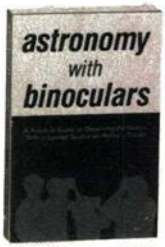
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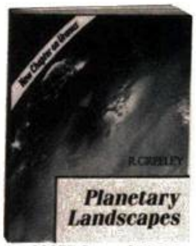
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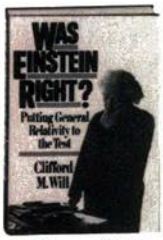
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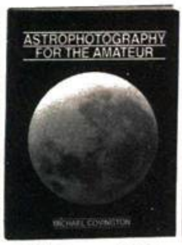
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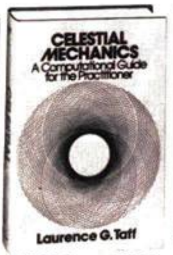
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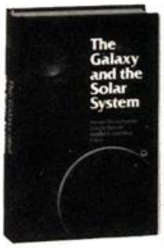
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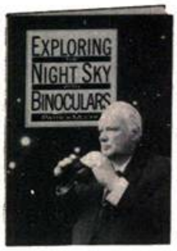
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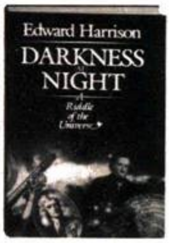
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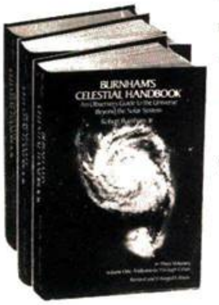
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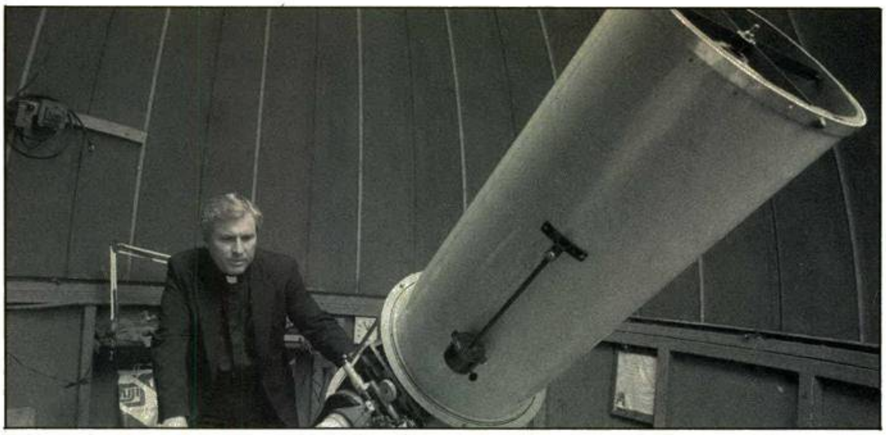
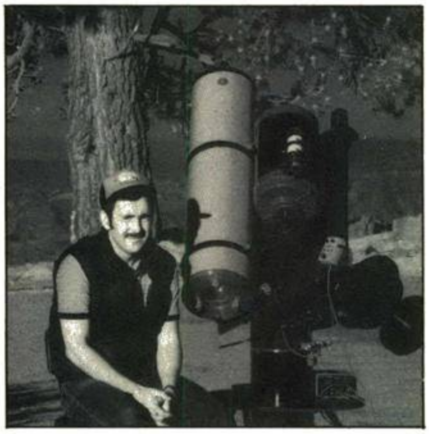


"Science doesn't go beyond what you can verify with your senses. It's possible to believe in both creation and evolution."
— Ronald Royer

M104; photo by Martin C. Germano



"I have no favorite objects to shoot, although capturing detail in planetaries and galaxies seems most demanding, and therefore is a good challenge."
— Martin C. Germano

"The lowliest amateur can make important contributions to science using inexpensive tools like a standard camera."
— Ben Mayer

in popularizing film hypersensitization and developed improved off-axis guiders, telecompressing lenses, and nebula filters.

Despite the commercial aspect of Lumicon, Marling is first and foremost a backyard astronomer. He is vice president of California's Tri-Valley Stargazers and often uses the club's 17.5-inch f/4.5 telescope for deep-sky observing and photography. His specialty is photographing planetary nebulae on color film. And he is so involved with photographing planetaries that he has applied for permission to use a telescope at Mauna Kea Observatory in Hawaii and has traveled there several times for astrophotography sessions. (See "The Incredible Skies of Mauna Kea" by Marling, April 1982.)

Marling is clearly passionate about astrophotography, but "capturing a lovely object on film and sharing celestial beauty with others" is what drives him to photograph the sky. As far as his own observing goes, Marling said, "I like to see faint objects visually that have always been thought too difficult to see. Astronomical photography has improved my life by providing a creative outlet. Besides, who can beat the feeling of standing underneath the Milky Way Galaxy on a clear, dark night?" he said.

Another Californian, Ronald Royer, is not a professional scientist and approaches astrophotography from a different angle. The fifty-five-year-old astronomer is best known for his experiments with tricolor photography, a process that utilizes three black-and-white images made with different filters to produce a single, dramatic color image. When he is not taking photographs of the sky, Royer is pastor of the San Pancratius Church and School in Lakewood, California, where he serves a congregation of 2,700 families.

Father Royer's 12.5-inch reflector lives in a dome on the rectory grounds. He is surprised at the success of photographing some objects from a light-polluted location less than twenty miles from central Los Angeles. Royer is proud that his photograph of Comet Halley, made on February 24, 1986, was helpful to astronomers studying dust outbursts from the comet's nucleus. But for deep-sky photography Royer travels between two and six hours away from the Los Angeles area in search of a dark sky.

An avid backyard astronomer since 1946, Royer is often asked whether or not his vocation and avocation cause any philosophical conflict. "Science doesn't go beyond what you can verify with your senses," Royer responded. "Religion goes beyond that, to faith. Catholics have never relied on the Bible alone, because we have many traditions. It's possible to believe in both creation and evolution, if evolution was God's way of creating Earth."

Another Californian, sixty-year-old Ben Mayer, was attracted to astrophotography for a much more worldly reason. "I started out in astronomy watching starlets around swimming pools from my home in Bel Air," he said. He then turned his telescope toward the stars and began taking photographs.

Mayer gained recognition after recording a series of photos showing Nova Cygni 1975. Made with a camera designed by Mayer to record meteors and mounted on the roof of his house, the photographs showed Nova Cygni brightening from invisibility to a naked-eye star. Astronomers gained valuable insights into the behavior of Nova Cygni by studying these photographs, which Mayer had thrown out because they did not show any meteors! He retrieved them at the last minute upon learning of the nova.

An industrial designer by trade, Mayer has built several unique devices for astrophotography and promoted their use in PROBLICOM, a search network for backyard astrophotogra-

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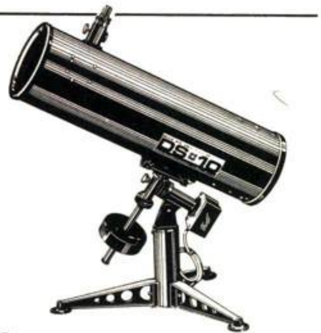

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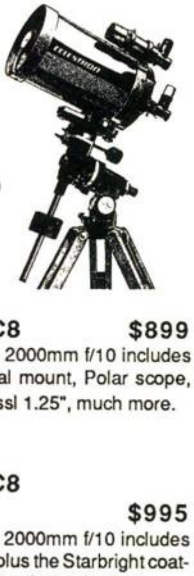

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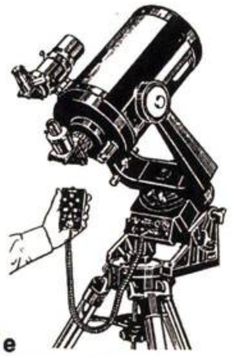

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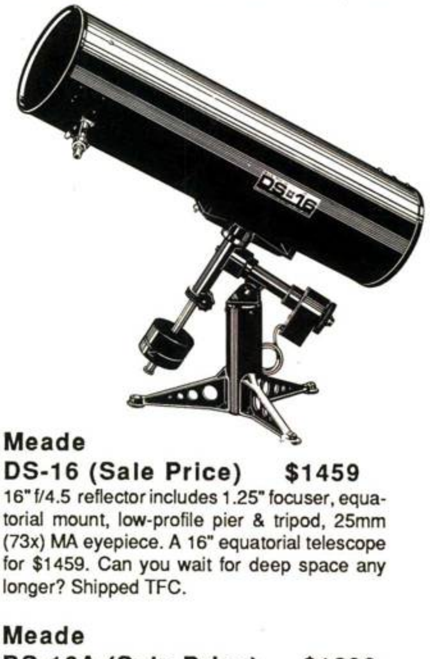

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Globular cluster M22; photo by Rick Dilsizian

> **"Deep-sky objects present the greatest challenge to me as well as the greatest satisfaction. The anticipation of seeing what the film has recorded over a long exposure is tremendously exciting!"**
>
> *— Lee C. Coombs*

> **"Schmidt cameras don't have a shutter mechanism. My wife Pam, also an avid backyard astronomer, acts as the shutter mechanism."**
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> *— Rick Dilsizian*

> **"I enjoy being on the cutting edge of technology with new films, new developers, and new techniques. After gas hypering Konica films I had to throw away my cold camera!"**
>
> *— Bill Iburg*

phers. PROBLICOM is short for projection blink comparator, a device that allows quick and easy comparison of two images of the same area of sky. (This device is the same type that was used in the discovery of Pluto.) With this equipment backyard astronomers can take photographs of sky and "blink" them to see if anything changed or moved in the field of view. Variable stars, novae, or supernovae and the motions of asteroids, comets, or planets can be detected this way.

The use of two more Mayer devices, a STEBLICOM (stereo blink comparator) and VIBLICOM (video blink comparator) has allowed backyard astrophotographers to seriously pursue their own discoveries of objects that change in the sky. Mayer is also the author of several astronomy books, including *Starwatch* and *Astrowatch*.

Mayer currently keeps busy photographing deep-sky objects from his observatory in Lockwood Valley, which is about one hundred miles north of Los Angeles. Searching for novae, comets, and asteroids in his photographs with his blink comparator keeps Mayer happy. "My greatest joy in the PROBLICOM network was independently discovering Uranus on one of my earliest pairs of slides," said Mayer. What excites him about astronomy? "The fact that even the lowliest amateur can make important contributions to science using inexpensive tools like a standard camera."

Martin C. Germano, a thirty-nine-year-old postal clerk, lives across town from Mayer in the suburb of Thousand Oaks, California. Germano became interested in astronomy twenty-one years ago and has been taking astrophotos for the last eighteen years. He is an active member of the Ventura County Astronomical Society. His skills in astrophotography are self-taught, and Germano doesn't shy away from admitting he's committed all of the classic astrophoto blunders at one point or another. "I've done all the bloopers: the usual 1/1000-second deep-sky shot guided for another 30 minutes, dozed off during an exposure, guided perfectly for 90 minutes but had the object placed outside the field of view, developed film at too high a temperature and dissolved the backing — all the textbook errors."

Yet Germano's successful shots are among the best. He has a roll-off roof observatory in his backyard, which he uses nightly for viewing the sky. For deep-sky photography, which he usually does with an 8-inch f/5 reflector and hypered Tech Pan film, Germano travels one hundred miles north to the summit of Mount Pinos. "I love astrophotography because of its inherent challenge in recording deep-sky detail not visible to the eye and faint planetary detail visible to the eye but difficult to capture on film," he said. Unlike many backyard astronomers, Germano doesn't play favorites. "I have no favorite objects to shoot, although capturing detail in planetaries and galaxies seems most demanding and is therefore a good challenge."

A close friend of Germano's, astrophotographer Lee C. Coombs, lives in San Luis Obispo, California. Their correspondence, in fact, typifies the close comraderie that pervades the world of backyard astrophotography. Despite their different backgrounds and outlooks on life, astrophotographers are driven by the spirit of adventure, which forges an unspoken bond, and they enjoy communicating and competing with one another. Lee Coombs is a forty-seven-year-old professor of chemistry at California Polytechnic State University. He has been drawn to backyard astronomy ever since the early 1950s and finds it hard to resist.

Two to six times a month Coombs photographs the sky with a 10-inch f/5 reflector in his backyard roll-off roof observatory. Because he lives less than a mile from the Pacific Ocean, dew is a problem. But he recently built a special low-voltage heater for the telescope's primary mirror. "It has alleviated the problem without affecting image quality," he said. Light pollution is also a slowly increasing concern at Coombs' site. "I must wait for optimum conditions and placement of the object I want to photograph to get reasonable results," said Coombs.

Although he enjoys photographing all types of objects in the sky, Coombs said, "deep-sky objects present the greatest challenge to me as well as the greatest satisfaction. The anticipation of seeing what the film has recorded

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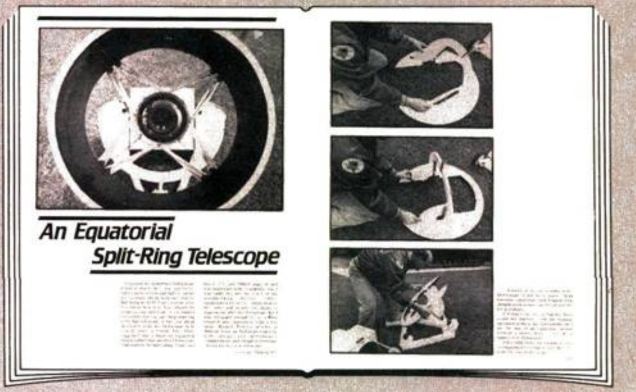
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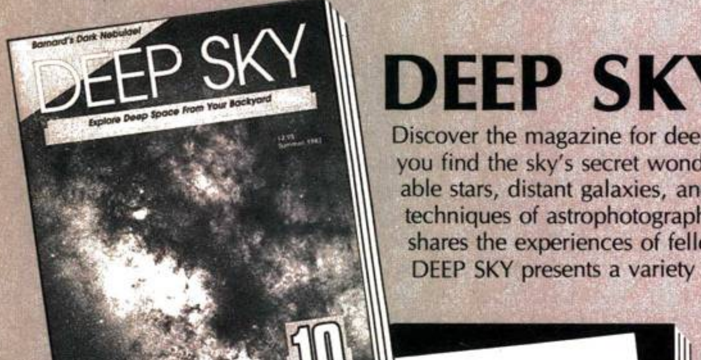
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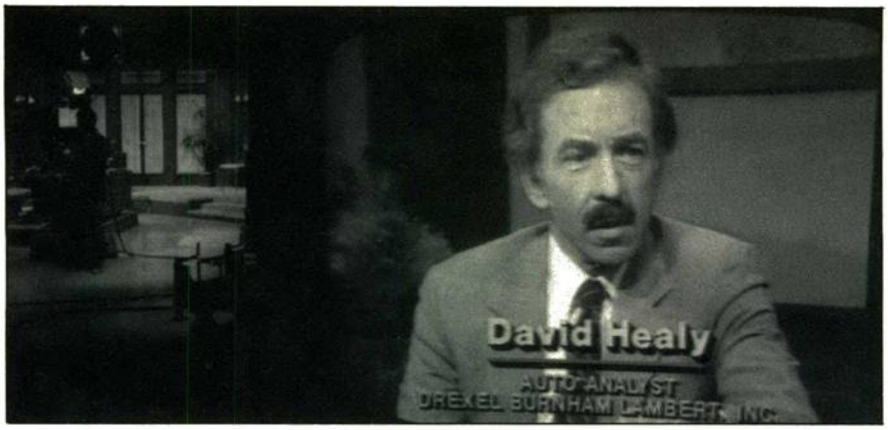
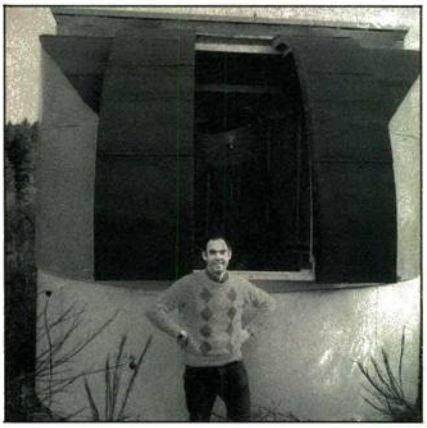


"The skies are particularly good from my mother-in-law's backyard if I can get Sheriff Wilson, who lives next door, to turn off his mercury vapor light."

— David Healy

Omega Nebula; photo by David Healy



"I love astronomy and love promoting it. It makes me feel like a pioneer."

— Jack Newton

over a long exposure is tremendously exciting!"

Astronomy is a big part of Coombs' life. "I have made many friends who share this hobby and have gained enough knowledge of the subject to teach a course in astronomy. But the friends are the most important part," he said.

A transplanted Californian who now lives in Pendleton, Oregon, Bill Iburg specializes in color images. Iburg, forty-two, entered the hobby in 1959 when he bought a small telescope with money he earned selling newspapers. Soon 4-inch, 6-inch, and 8-inch telescopes followed and Iburg became deeply involved with observing the sky. The lunar eclipse of May 1975 launched Iburg into astrophotography with his new 8-inch SCT. He now uses that telescope, 5-inch and 14-inch SCTs. and 5.5-inch and 8-inch Schmidt cameras.

Iburg owns a family home rental business that allows him the flexibility to do astrophotography when the sky is clear. He does not have a backyard observatory but drives about twenty minutes to reach the Blue Mountains, where he sets up his telescopes. Iburg's ten-year-old son often accompanies him on these trips.

The development of good commercial cold cameras in the late 1970s allowed Iburg to concentrate on high-quality color photography. "I enjoy being on the cutting edge of technology, with new films, new developers, and new techniques. My most exciting discovery was the new series of Konica films that produced results so impressive after gas hypering that I had to retire my cold camera!"

There is a difficult side of astrophotography that balances the excitement, however. "Many times during the past twelve years I have been strongly tempted to throw in the towel. It is a hard thing to do without becoming maddeningly frustrated. But I always find myself returning to astrophotography because of the sheer excitement of it!"

Rick Dilsizian, a college professor who teaches math and computer sciences in Valhalla, New York, is atypical of prominent astrophotographers simply because he is an easterner. Dilsizian, forty, has been interested in astrophotography for fifteen years and has the same type of equipment Iburg has: 5-inch, 8-inch, and 14-inch SCTs; and 5.5-inch and 8-inch Schmidt cameras. He became interested in shooting the stars when he tried to photograph the Moon with a Brownie camera in 1962. "My first astrophoto didn't turn out too well," he admitted.

Dilsizian concentrates on Schmidt camera photography and has produced hundreds of wide-field photographs of deep-sky objects and comets using his 8-inch camera. During the apparition of Comet Halley he was actively involved in monitoring the comet for the International Halley Watch, photographing every clear night, and sending the results to the Halley Watch headquarters at the Jet Propulsion Laboratory.

"The trickiest problem with using Schmidt cameras is that they don't have a shutter mechanism," he said. "My wife Pam, also an avid backyard astronomer, acts as the shutter mechanism."

Also a New Yorker, fifty-year-old David Healy is a securities analyst for Drexel, Burnham, Lambert in New York City. He is an authority on the automotive industry and has been interviewed on the *Today* show, *Good Morning America*, *Wall Street Week*, and the *CBS Evening News*.

How does a busy Wall Street analyst in light-polluted New York City do astrophotography? "We have some dark sky in the family," Healy explained. "My mother-in-law lives in Naco, Arizona, about one hundred miles southeast of Tucson. The skies are particularly good from her backyard if I can get Sheriff Wilson, who lives next door, to turn off his mercury vapor light."

Healy said that the publicity surrounding Comet Kohoutek in 1973, plus a prior interest in photography, thrust him into astrophotography. He uses a 14-inch SCT and an 8-inch Schmidt camera for deep-sky photography in Arizona. The exciting part, the thing that makes him travel so far and spend so much effort on his hobby, is "achieving deep, high-quality photographs that bring out detail in objects otherwise difficult to see."

Forty-five-year-old Canadian astrophotographer Jack Newton is the author of several books on the stars, including *Deep Sky Objects* and *The Cambridge Deep Sky Album*. Residing in Victoria, British Columbia, where he is manager of the local Marks and Spencer department store, Newton has a backyard observatory that offers a dark, if only occasionally clear sky. The observatory contains a 3/4 ton, 20-inch f/5 reflector that must be

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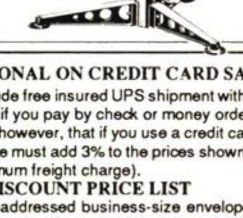

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heated continually to prevent moss growth from the damp surrounding air.

Interested in the sky and stars since age twelve, Newton became an astrophotographer because he "wanted to prove to my friends that I was really seeing what I claimed to." His techniques in recording the stars were entirely self-taught, but along the way he developed his own cold cameras, hypersensitizing chamber, and off-axis guider.

"I continue to photograph deep-sky objects because of the anticipation of seeing the results of my work," he said. Newton's wife Alice frequently helps with photography and keeps track of records while bundled in an electric blanket inside the observatory's dome.

Newton's only regret is a photo he took of the galaxy NGC 4490 in the spring of 1982. Unknown to Newton, the galaxy contained a supernova that had not yet been discovered. "I was too cheap to take the film in before the roll was used up," he said, and he missed out on credit for the supernova's discovery.

Aside from this disappointment, however, astrophotography continues to be a driving force in his life. "I love astronomy and love promoting it," said Newton. "I feel fortunate to be engaged in a hobby I enjoy that doesn't involve a large percentage of the population, because it makes me feel like a pioneer."

This pioneering spirit pervades the lives of each of these accomplished astrophotographers. Creating images of the vast universe for their own enjoyment and for the enjoyment of others enriches the lives of all of us.

Robert Reeves
San Antonio, TX

It Was Just One of Those Nights

Sooner or later every astronomer has one of those ill-fated nights when staying home would have been much smarter than plying the skies with a telescope. My night came last January.

By profession I am an officer in the Canadian Armed Forces, stationed at Canadian Forces Base North Bay in central Ontario. The city of North Bay is situated in a lush, mildly populated bushland well away from the metropolitan jungles lining the south of the province. The skies in the North Bay region are marvelous: exceptionally dark, spectacularly clear, and a boon for an amateur astronomer.

Central Ontario, however, gets some serious winter weather. North Bay, in particular, is far enough north that its winters tend to alternate between hefty, city-stopping blankets of snow and fierce, bone-chilling wind.

On my night the wind was in full force. That night the mercury barely poking its head above −13° F. Common sense tells us to remain indoors, all warm and toasty, when temperatures like this exist outside. But astronomers don't always listen to common sense.

The Milky Way gleamed overhead, almost fluorescent in appearance. The Andromeda Galaxy was plainly visible to the naked eye, and the stars seemed to reach out from the dark and touch the observer. I couldn't resist such a night.

Bundling up in nine layers of clothing, I loaded my trusty 6-inch f/6 Edmund Scientific Newtonian telescope into my car and drove around to the far side of the base via a public road. I set up shop at 9:45 p.m. and for the next hour lingered over the most beautiful sky I had seen in a long time. The Pleiades leaped through my eyepiece, while Orion took on a three-dimensional appearance. Double stars, separated by as little as 2 or 3 arcseconds, were cleanly split, and I saw structure in M31 I had never observed before in my 6-inch scope. What I saw was so magnificent I was not even aware of the cold.

At 10:45 p.m. the glare of headlights from a passing city bus interrupted my observing session. While I waited for the bus to pass, I reflected for a moment on what I had seen and mused over what to view next. I gazed up at Gemini and thought I would check out the constellation's stars for companions. Hunting for companions is a favorite activity of mine.

As the bus passed from sight, I returned to the eyepiece and wandered among successively dimmer stars during my hunt, coming eventually to 64 Gemini, a 5th-magnitude star that forms a rough equilateral triangle with Castor and Pollux.

For some reason I was having trouble finding 64 Gemini in my focus finder, so I knelt behind the scope and carefully sighted along the tube towards the star. This is when it happened.

Over the previous hour much of the moisture from my breath had accumulated on my moustache and, as I deftly aligned the telescope, the right half of my moustache brushed against the metal mirror cell — and instantly froze to the cell! I did not realize this had occurred until I tried to stand up and found the telescope firmly attached to my face. Gently, carefully, I tugged my head backward, but it was hopeless. I was stuck. I mumbled an expletive.

Regaining my composure, I took my right glove off, grabbed my frozen hair, and yanked with all my might. A thick tuft came out in my fingers. Through the tears welling up in my eyes I could see some strands still clinging to the mirror cell — though no longer to my face — and I tasted a warm, salty trickle of blood. I stood up and gingerly dabbed at the blank spot where a healthy swath of moustache used to reside. The area felt warm and was beginning to swell.

Then my observing site suddenly exploded with light. It was as if the Sun had abruptly come out at 11 p.m. I darn near jumped out of my skin.

From behind the light, a voice called out: "Move away from that rocket launcher! Keep your hands where I can see them!"

Rocket launcher? I hesitated. The voice repeated the demand. The light enveloped me from two sources, one on the other side of the locked gate, the second from across the public road. Out of the latter sea of light I could discern a figure slowly approaching, and, as he neared, I could see he had a pistol drawn and pointed at me. I realized he was a military policeman from the base.

Little did I know that while I was sorting out my moustache, the city bus driver had reported a suspicious person armed with what looked like a rocket launcher, lurking about the back of the base to the military police. The MPs instantly dispatched two jet black patrol cars to the scene, which crept up to the site with their lights off to achieve the maximum amount of surprise. They certainly surprised me — when the MPs flicked on their searchlights I almost wet myself.

A bit incensed and smarting from the moustache affair, I blurted: "This isn't a (expletive deleted) rocket launcher! It's a telescope."

Puzzlement on his face, the MP looked at the "weapon," then at me, then back again at the weapon. Upon inspection of my military identification and even closer scrutiny of the "launcher," he reholstered his pistol, the searchlights were snuffed out, and a sigh of relief was breathed by all.

Stone blind from the glare of the searchlights, I nevertheless made a valiant attempt to show our military's finest the Orion Nebula and M31 and then sent them on their way.

Silently standing in the dark, I knew the "jig" was up. My night vision had been blasted away, half my moustache was missing, and the temperature had sunk to −22° F. Fate was telling me to pack up my toys for the night.

I did just that.

Doug Newman
Hornell Heights, Ontario, Canada

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ASTRONOMY
In Focus

Another Eclipse Junkie

Sir / I enjoyed reading "Confessions of an Eclipse Addict" by Joel K. Harris (Gazer's Gazette, January 1988). The only solar eclipse I've ever viewed was from the cut wheat fields southwest of Goldendale, Washington.

The day before the eclipse it was raining. We visited the local airport to secure the services of an aircraft to see the eclipse, but this proved futile.

The weather in the Pacific Northwest was predictable — rain! There was a 10 percent chance of clear skies. But what occurred over the next twenty-four hours was nothing short of miraculous. An overheard conversation led us to a very detailed weather forecast, so early the next morning we headed 127 miles west of where we were staying.

By this time only the stratus at 7,000 feet had dissipated; the cirrus at 31,000 feet still persisted. As we climbed slowly out of the Columbia River Gorge in heavy traffic, we spotted a patch of blue sky to the west. But we were restrained from moving toward the blue sky by the highway's northerly course until we came to an exit sign and were able to turn toward the open sky.

Thirty minutes later, after first contact had already occurred, we stopped, staked our claim, and hoped to see totality. Five or ten minutes before second contact the last thin curtain of cirrus moved away and put the celestial duet in full view 12° to 15° above our eastern horizon.

What we saw and photographed can only be felt and never completely described. We were hit and run victims of the lunar shadow, yet little physical evidence remained of the event. It was a celestial paradox: effects so profound and deeply felt and yet not a single downed fence post or broken shaft of last season's wheat.

I've shared slides of this eclipse with about a thousand students since then. I can't talk when I show the slides of totality. The students' reactions are interesting: most applaud spontaneously.

Paul L. Graves
San Jose, California

An Audio Observer's Notebook

Sir / After reading Andrew M. Thorpe's fine article, "Should You Keep an Astronomical Notebook?" (Equipment Atlas, January 1988), I wondered how many other amateur astronomers have arrived at the same "compromise" I have used for several years.

As an alternative to keeping a fully written journal of my observations, I use a microcassette tape recorder with a voice-activated recording circuit. I simply talk about what I am seeing as I observe — without ever having to leave the eyepiece.

Then, at the end of each session, I catalog the tape chronologically in a small notebook, index the tape with the counter on the cassette recorder, and include a brief description of the session. I also include any drawings that I make in this notebook, although more often than not I photograph what I see. The tape, of course, makes it easy to record full information for each exposure.

I'm the first to admit this system probably isn't as good as keeping a fully documented journal, but it is far better than keeping no record at all. In addition, it offers some interesting possibilities a written journal does not offer.

For example, one of my favorite tricks is to set up my radio receiver near the telescope and tune to WWV (the official U.S. time signal) with the volume set just below the activation level of the tape recorder. As I start speaking, the recorder also picks up the broadcast, and I then have a time standard built into my journal for precisely timing events.

The tape also records some of my emotional reactions while observing, which makes interesting sessions more enjoyable to relive months or years later.

Thad Byars
Killeen, Texas

Not Afraid of Loneliness

Sir / If the primal fear ("The Primal Fear: Are We Alone?" by Frank Apsi-Ridolfo, Forum, December 1987) of being alone in the universe is the real reason we are compelled to explore space, why hasn't NASA made more of the fact when seeking appropriations? Show me the astronauts who became astronauts because they were afraid that intelligent life may not exist beyond Earth. Who's afraid of being alone when Earth teems with companions? The greatest fear for some people is that we may *not* be alone.

I think exploration — be it pressing out of Africa, sailing across seas, or rocketing to planet X — has little to do with primal fear and a lot to do with primal curiosity, along with excitement, hope, search for fame, and strategy. Even if we find companionship on planet X, we will be compelled to continue to explore, because we will remain curious about planets Y and Z and beyond.

Evans H. Burns
Sherborn, Massachusetts

Stop-Down Mask Works

Sir / Thank you for printing M. Leon Knott's letter on stop-down masks (In Focus, December 1987). I have an 8-inch Dobsonian with a 10-inch tube, and a Frisbee makes a perfect dust cover.

After reading Mr. Knott's letter, I thought, what the heck, and found an old Frisbee.

I cut a hole just a shade over 3 inches in diameter. This device really came in handy on a night when the sky was very dark but the seeing was poor. Epsilon Lyrae was a big blob in my high-powered eyepiece, but when I put the Frisbee over the opening, presto! I split the two pairs of stars with ease.

I also split Castor easily. And Jupiter was easier to study, because it wasn't so glaringly bright anymore.

I have one question though. Does Mr. Knott mean his stopped-down telescope resolves at the theoretical limit of the full aperture or of the stopped-down aperture? Because the 3-inch mask can split Castor implies that the resolution is close to the limit for a 3-inch telescope.

Tom Rankin
Highland, New Jersey

— Your telescope will have the resolving power of the stopped-down aperture. Stopping-down seldom helps a good mirror, but, as you have seen, a small aperture performing near the theoretical limit can do more than full aperture from a poor mirror.

A Soviet Fireball

Sir / I witnessed a spectacular fireball December 12, 1987. I had just started an exposure of Comet Bradfield when I noticed a bright light in the sky to the north. I turned in that direction and saw a fabulous fireball about 40° high just below the dipper of Ursa Minor. It was traveling east almost on a horizontal flight path. Above Ursa Major it burst into a huge ball of sparks and orange light and left a gray cloud of smoke. When it burst, it split into two separate pieces, one on top of the other, and maintained the same straight path while losing altitude.

I watched it fly below Orion and disappear. A few moments later it reappeared and I watched the dim reddish fireball go down below the horizon in my binoculars. I stood for the longest time knowing that what I saw or at least what I *thought* I saw was the greatest meteor of all times.

On the front page of the local newspaper the next morning I read that what I had seen was a Soviet rocket used to launch a satellite earlier in the week. The star of my show was the re-entry of that rocket.

Robert Asher
Cheyenne, Wyoming

Tracking *Apollo 13*

Sir / I would like to correct some statements made by Paul Maley in "Globetrotting Observer Paul Maley: Chasing the Fleeting Moment" by Robert Reeves (Forum, November 1987) about the events connected with the optical observations of the *Apollo 13* Command Module oxygen tank explosion with the Johnson Space Center's 16-inch telescope.

The telescope was not idle, as Mr. Maley stated in the interview; it was in active use and had previously provided optical/video tracking of the *Apollo* translunar flights.

Mr. Maley also did not "get" the telescope trained on anything. The telescope was already in active use tracking various parts of the *Apollo 13* mission on its way to the Moon. Mr. Maley, along with others, was a guest observer out of courtesy to his reputation and interest in the optical tracking of orbital objects and because he was a participant in the then active Lunar Transient Monitoring program, in which the 16-inch telescope was also utilized.

Mr. Maley did not provide any "look angles" to point the telescope; these data were obtained directly from the Mission Control Center, which is located some two hundred yards from the tracking facility.

Andy Saulietis
Manager, ASD Tracking Laboratory
Johnson Space Center
Houston, Texas

Bewildered No Longer

Sir / The cartoon of the bewildered telescope shopper that opens "ASTRONOMY's 1987 Guide to Telescopes" accurately depicts the plight of many amateurs trying to decide which telescope to buy. The special section was very informative and frank — and well timed — because I plan to invest in a large telescope soon.

Steve Summitt
Antioch, Tennessee

Behind the Scenes

Get Ready for Mars

With one hand I clung to the stepladder and, my eye to the eyepiece, I studied the ruddy planet. With my other hand I clutched a pencil and a 3x5 file card to draw whatever surface features there were to see. The luminous disk trembled in the chill winter air as I sketched the deserts and plains of a distant world.

The year was 1963: Mars reached opposition in February. I was a high school junior with a homebuilt 8-inch f/10 Newtonian, a tall telescope with a plywood tube. Every clear night that winter I sketched the Red Planet, thrilled with the sight of the faint grey-green markings and the gleaming polar cap.

But Mars presented a problem for me. At opposition Mars is highest in the sky at midnight, and this was too late for me to stay up on school nights. So I would go to bed early. But at midnight I would quietly get out of bed, put my bathrobe over my pajamas and boots over my bedroom slippers, and sneak outside to the telescope.

The problem with observing this way was the cold. If there was no breeze, I'd be fairly comfortable, but even a light wind made my "observing runs" tests of endurance. Earmuffs helped keep me warm, but I couldn't wear gloves while I made my drawings, so my fingers were always numb.

But I loved every second of it.

You don't have to freeze to observe Mars. In fact, as Jeff Beish points out in this month's Gazer's Gazette, you don't even need dark skies. "For the majority of us who live in cities, the opportunities for deep-sky observing are limited, but you can observe Mars from anywhere. Even New York."

To further help potential Mars observers, two observing guides will soon be out. The Planetary Society plans to publish *The Mars Observer's Handbook* by Jeff Beish and Charles Capen this spring. It will provide considerably more detail than we could fit in this month's Gazer's Gazette. The second, *Observing and Photographing the Solar System* by Tom Dobbins, Donald Parker, and Charles Capen (Willmann-Bell), collects decades of practical planetary observing experience into a single volume. Watch for both.

I'll conclude with a word to the wise on this month's sidereal clock project (page 44): If you're not familiar with electronic circuitry, find someone to help you. It's not difficult if you know what you're doing — and the clock works beautifully — but there are plenty of pitfalls for the unwary.

Sincerely,

Richard Berry

Richard Berry
Editor-in-Chief

Personal Planetariums: The Night Sky in Your Computer

If you're thinking that there seems to be a lot of astronomy software on the market these days, you're right. In fact, there's a whole line of new programs out there — too many to keep up with.

Last December NASA and the Aerospace Education Services Project at Oklahoma State University issued the first edition of *Software for Aerospace Education*, a bibliography of educational astronomy and aerospace software. The bibliography lists 101 different software programs, everything from orbital mechanics to star plotting. (This publication is available to teachers; contact the Teacher Resource Center at the NASA center in your region of the United States.)

The programs featured in NASA's bibliography represent no more than a drop in the flooded astronomy software market. Out of this sea of software some of the most popular with amateur astronomers are the ephemeris or planetarium programs. Planetarium programs allow you to do things like compute the Moon's phase as it appeared on December 16, 1773, plot planet positions for the year 2125, or display star maps complete with the positions of deep-sky objects and variable stars. Though there are far fewer planetarium programs than general space-science programs, that doesn't make the selection any easier. The problem is that the casual computer user *cum* amateur astronomer must consider an astounding spectrum of available features. These range from simple text listings of the characteristics of stars and other celestial objects to full graphic representations of the night sky.

In an effort to put some method into the madness (or maybe vice versa), we have reviewed a dozen software planetarium programs that we believe will interest the computer-equipped amateur astronomer. By no means is every planetarium program represented here. As we have said, there are just too many software programs out there to keep up with. (For a more complete list, consult software bibliographies such as the one published by NASA.) Nevertheless, these programs offer a fair sampling of what's available.

In making our selections, we sought programs that appeared to be practical, powerful, and comprehensive. Most of these programs have been recently published; others are new versions of older programs.

We've included as many planetarium programs as possible. But if your favorite program is omitted, don't despair: either we reviewed the program in a previous issue or we didn't receive a copy of the program in time for this review. We also tried to stick mainly to the night-sky-in-your-computer-type programs. Astronomy games, educational astrophysics, and programs designed strictly for learning the constellations or plotting solar system bodies were not included.

You'll notice that many of these programs have been designed for IBM compatibles. That's not to ignore the many programs out there that will run on other machines, but it does make a statement about which machines many vendors are targeting their programs for. Among the more popular non-IBM programs we are aware of are *Andromeda* for the Apple, *The Observatory* for the Apple, and *Astroview* for the Commodore and the Apple. There is also a suite of relatively specialized programs available from Zephyr Services (which produced *Astro-Finder,* reviewed here) that will run on the Apple and Commodore machines.

Some of the programs reviewed here are available in multiple formats. These include *TellStar*, which is available for the Apple Macintosh and the Apple II, and *Sky Travel*, which comes in versions for the Macintosh, Atari, and Commodore computers.

— *Jeff Kanipe*

Astro-Finder for IBM compatibles, (Zephyr Services, 1900 Murray Avenue, Dept. B, Pittsburgh, PA 15217, 1987), $69.95.

If you're looking for a planetarium program that is a good value for the money, *Astro-Finder* is the one. The database includes nearly 1,600 stars, the Messier catalog, and a special database of comets and deep-sky objects. The limiting magnitude is 5.0.

Astro-Finder can generate star charts in four formats: half-screen skyview with half-screen observing data, full-screen skyview, full-screen view with 1/8-degree resolution, and coordinate grid that can either be shown alone or superimposed on the skyview. If desired, up to twenty charts can be preloaded into a batch file to be executed automatically. *Astro-Finder* uses Mercator projection.

An *Astro-Finder* feature that outshines the other programs is the star catalog. The manual includes a fourteen-page star catalog, but the database can be used to generate a star catalog on the screen or a thirty-page hard copy.

The feedback I've received from other computer users is that *Astro-Finder* works satisfactorily with Tandy 1000 and DMP 130 computers.

— *Michael Krochmal*

AstroSoft Computerized Ephemeris for IBM compatibles, (AstroSoft, P.O. Box 4451, Hayward, CA 94540-4451, 1986), $25, suggested.

Although it doesn't contain any flashy graphics routines, the *AstroSoft Computerized Ephemeris (ACE)* is rich in information.

ACE consists of three sections : ACECALC, ACESOLAR, and ACECAT. The first part is the ephemeris that calculates all the normal astronomical stuff: right ascension, declination, rise and set, phases, etc. ACESOLAR contains information about all the bodies in the solar system. There are reams of data on the Sun, Moon, planets, and planetary satellites. The stuff about the satellites needs a bit of updating now, but it's still pretty good.

There are a few areas that could be improved. One is the data input. The input fields are not aligned with the prompt fields, which makes input look messy. Errors just wipe out all input, and you have to start from scratch. And when the output is generated, the input disappears from the screen.

On the positive side this program does recognize input of the nonexistent year 0 as an error (most of the other programs do not). The database is also pretty good: over two thousand deep-sky objects, all stars brighter than magnitude 2, detailed commentary on over four hundred objects, data on over one hundred objects with common names, and over one hundred double stars. There's a perpetual calendar that operates between the years 32,000 B.C. and A.D. 32,000 (which should be enough of a time span for most purposes).

This is user-supported software, which accounts for the low $25 suggested price. The program can be obtained free from AstroSoft by sending two double-sided, double-density floppies in a diskette mailer with a return address label and correct postage. If the user finds the program to be of value, a voluntary, tax-deductible donation of $25 to the vendor is encouraged.

— *Michael Krochmal*

Celestial Basic for Commodore C64 and C128, Atari 800XE/XL and 1200 XE/XL, Apple II, and IBM compatibles, (American Only Inc., 13361 Frati Lane, Sebastopol, CA 94572, Atari version, 1987), $49.95 for most versions.

Celestial Basic is a companion to Eric Burgess's popular book, *Celestial Basic, Astronomy on Your Computer* (SYBEX Inc). The book describes and lists twenty-six educational and utility programs for amateur astronomers. However, typing the programs from the book into a computer can be a time-consuming and error-prone task. *Celestial Basic* software overcomes

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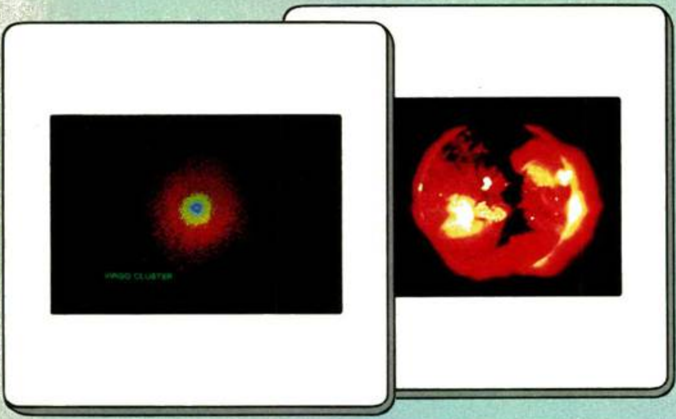

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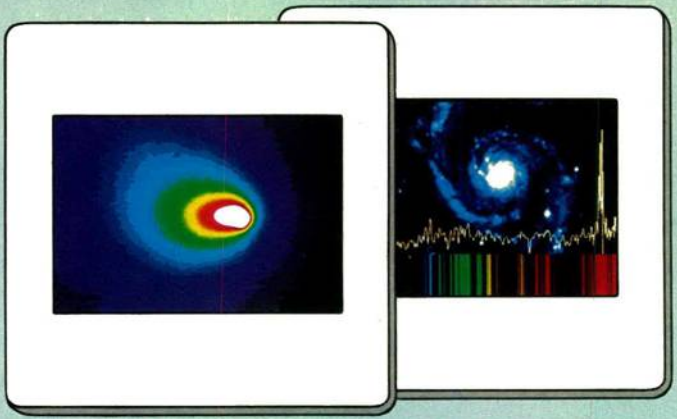

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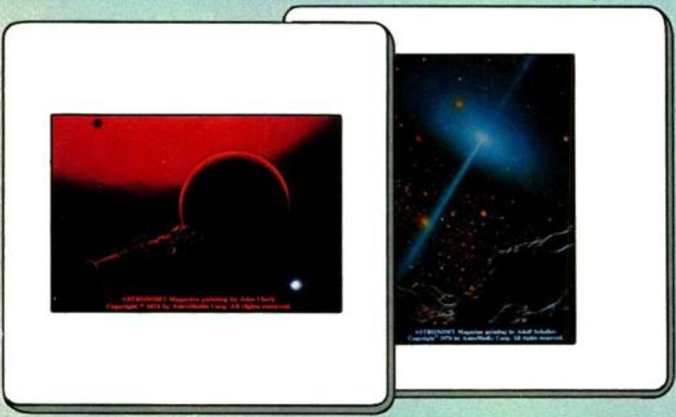

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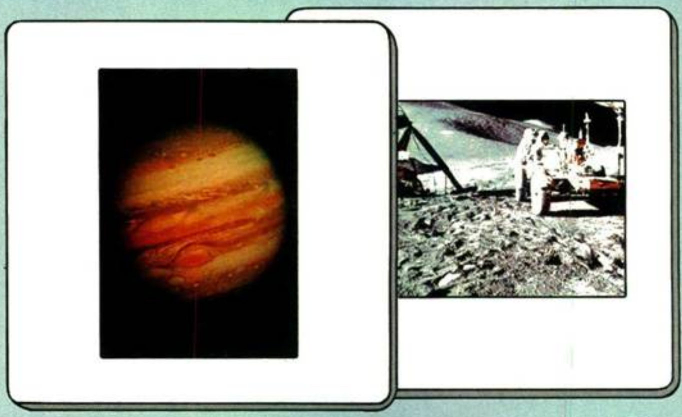

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these shortcomings by furnishing disks containing all the programs in the book.

The set of twenty-six programs covers a wide variety of astronomical applications. These are grouped into four categories: Moon, planets, time, and general and tutorial. Program selection and execution is facilitated by a series of menus. Some of the more interesting programs are lunar phases; sky plots; time conversions; Jupiter satellites; umbral lunar eclipse predictor; Mars opposition finder; rise, set, and transit times for the Moon, Sun and planets; and updating star coordinates.

Unfortunately the *Celestial Basic* programs have a number of shortcomings. The user interface and error handling capabilities are quite limited. Input common to many programs such as longitude, latitude, and time zone must be re-entered as you switch programs. The program's accuracy is acceptable only for casual observing, not for more rigorous use. The sky chart graphics are rudimentary and it is often difficult to identify constellations. And, finally, it is unclear how to account for daylight savings time on input of local time and time zone.

To its credit, though, *Celestial Basic* software is one of the few commercial packages that provides a source code to analyze and modify. Because the Basic source code is furnished, you may correct many of the problems listed above or tailor the programs to meet specific needs. The availability of the source code is a strong selling point for someone wanting to learn how to program astronomical applications.

The programs closely match the source code in the book, but some improvements have been made. Because each of the programs is written independently of the others and only performs one function (e.g. determining lunar phase dates), the programs' logic accommodates itself to experimentation and study. Conversely, the programs are not as sophisticated as other integrated astronomical programs available on the marketplace. Multiprogram operation is cumbersome because program variables entered by the user, such as date, time, and observing coordinates, do not transfer from one program to another.

— Lawrence Paul

Deep-Sky Object Inventory for IBM compatibles, (AA Star Systems, P.O. Box 1042, Fair Oaks, CA 95628, 1987), $69.95.

Deep-Sky Object Inventory (DSOI) is a nonstellar, nonplanetary database oriented toward deep-sky objects. It is built around the Messier catalog, the New General Catalog, and the Index Catalog. Object output parameters include object, type, NGC number, the name of the constellation in which the object is found, and common names as well as others shown in the chart.

The database includes Southern as well as Northern Hemisphere objects. The source data was compiled from AA Star System's own observations as well as from research through current published data. Selected sets of data can be accessed by a process involving up to three selection criteria. These are selected from a list of five options: constellation (a list of eighty-eight), type of object (a list of five), maximum magnitude, Messier number range, and NGC number range.

As well as sending the data to the screen or the printer, you can transfer the data to an ASCII file. This file can then be accessed with BASIC, dBaseIII, or similar database programs. Unfortunately, when I dialed up a choice of 25.0 for maximum magnitude after selecting "Andromeda," "galaxy," and "spiral," the program went into a tailspin, indicating a lack of error discrimination. Apart from that, the program

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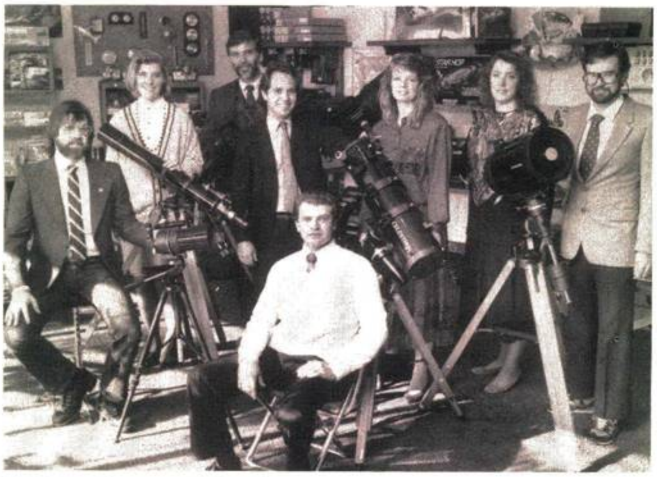

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looks like a useful acquisition for deep-sky observers.

— *Michael Krochmal*

Deep Space for IBM compatibles, (David Chandler Co., P.O. Box 309, La Verne, CA 91750, 1987), $49.

There is probably no better value in a star-charting program than *Deep Space*. Written and distributed as "shareware," *Deep Space* may be obtained free for evaluation from any owner. If you find the program useful, you should register it by sending David Chandler $49.

Deep Space does six things: it draws all-sky charts for any time and place, charts of any part of the sky in the coordinate system of your choice, 3-D star charts (a 3-D viewer is available for $10), graphic timetables of the planets, shows the planets in their orbits, and produces ephemerides for comets, and plots these on the star-chart or orbit-plan maps. Although screen representations of the charts are limited by the CGA graphics card, hard copy output exploits the full resolution of a 75-dot-per-inch dot matrix printer for a crisp 8" by 10" page.

The current database consists of 18,000 stars, but in his documentation Chandler said he plans to expand this to the quarter-million-star Smithsonian Astrophysical Observatory catalog plus the Simmons computerized NGC if program users are interested.

Deep Space is an excellent program for amateur astronomers and junior high and high school science classes. I particularly recommend that every astronomy club order a copy for its members.

— *Richard Berry*

Galileo for AMIGA personal computers, (Infinity Software Ltd., 1331 61st Street, Suite F, Emeryville, CA 94608, 1987), no price given.

Galileo can display 1,600 stars and simulate their magnitudes by sixteen levels of brightness. This results in one of the most realistic displays of stars I've ever seen on a computer screen. If you're going for realism, you can even select "skylight" to simulate urban sky conditions. In addition, the Messier catalog and 340 NGC objects are included in the database.

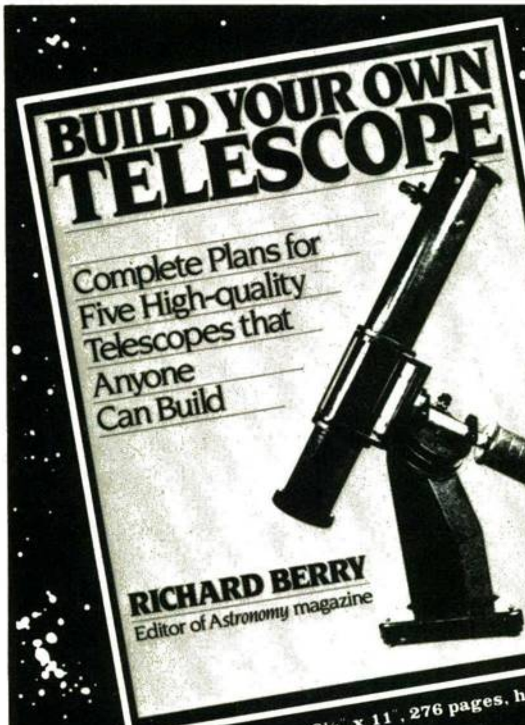
The software's algorithms are accurate enough for dates up to four hundred years past and in the future. Time and date are initially accessed from the computer's real-time clock and can be changed from the keyboard, but the time does not automatically update in real-time or accelerated speed while you watch. You have to call up the time-date window, enter the new time and date, and press the RETURN key.

To display planetary motion, the tracking function updates the positions of the planets in one-day increments and plots them on the starfield. You can also manually set up the planets using the mouse.

An interesting feature of *Galileo* is the telescope window. When it is activated, a small "TV set" appears on the screen. By placing the cursor near any solar system object on the starfield, an enlarged view of the object appears on the mini-TV. Close conjunctions, solar and lunar eclipses, and lunar and Venusian phases are also displayed.

The telescope has a few quirks though. For example, the angular separations of the planets seen on the starfield rarely match those seen on the TV, though Mars' angular size changes with Mars' proximity to Earth. The cursor never seems to really line up with the planets when you see it on the TV.

The strangest display is for solar eclipses. If you place the Moon at the center of the screen, a solar eclipse looks normal. However, if you locate the Sun at the center of the screen, the software plots the Sun in the screen's foreground and the Sun eclipses the Moon! Nice trick.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Galileo is an excellent package and the graphics are marvelous. I would really like to see an automatic time-incrementing function added, though, to make watching eclipses and occultations easier.

— James Bailey

LodeStar for IBM compatibles, (Stellatron, 122 C.R. 510, Durango, CO 81301, 1987), $56.75.

LodeStar simulates sunrise, sunset, twilight, planet positions, deep-sky objects, and the constellations. Its strong suit, however, may be the data it provides about the stars and Messier objects it displays.

LodeStar's database consists of 9,096 stars. Stars are displayed in three colors to show spectral ranges; faintest stars are visual magnitude 7.1. *LodeStar* can find and identify stars displaying star data consisting of the Henry Draper or Flamsteed catalog number, Bayer Greek letter, variable letter designation, the constellation, visual magnitude, color index, or spectral class, and whether a star is a double or a confirmed or suspected variable.

Messier objects can be found and identified with data consisting of the Messier number, visual magnitude, color index, angular size, and the type or classification description. The limiting magnitude for Messier objects is 12.7.

You might have to do some fussing around to get *LodeStar* up and running on your system. Right off the bat, if you don't have an 8087 coprocessor in your system, the program aborts. *LodeStar* makes use of a specially compressed database that would require eight double-sided, double-density floppies. Although *LodeStar* requires a color graphics adaptor (CGA) for the graphics screen, the program will work with Hercules graphics if the Hercules utility program "SIMCGA" is used to emulate the CGA.

— Michael Krochmal

P.C. Planetarium for IBM compatibles, (Light Software, 1850 Union Street, #252, San Francisco, CA 94123, 1985), $52.00.

This program contains the best pseudo-three-dimensional representation of the Earth's globe of all the programs I reviewed. The globe is used for determining the viewer's position if you don't want to be bothered with coordinates.

P.C. Planetarium is designed to draw sky maps from any point on Earth, for any moment from 9999 B.C. to A.D. 9999. The program lists all the visible constellations and will point out any constellation you choose on the screen's sky. If you specify the right ascension and declination of an object you want to locate, the program marks the position on the map and gives you the object's local coordinates for the viewer's specific time, date, and place. This is very handy for meteor and comet observers, among others.

The database contains nine hundred stars down to magnitude 4.5. Other features include the Sun, Moon, Halley's Comet, and the planets out to Saturn. Precession, proper motion, nutation, and aberration can be calculated by the program.

One interesting aspect about the operation of this program is that when the program is started up, it plots the star points on the screen by constellation. The name of each constellation appears at the top of the screen as the stars are plotted. Star maps can be printed out in about twenty minutes.

The print quality of the thirty-two-page paperback manual is excellent and the instructions are very clear. Although some may consider this a minor detail, having a well-designed manual is often the determining factor between pleasure and pain in learning a new software program.

— Michael Krochmal

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The Sky for IBM compatibles, (Computer Assist Services, Colleen Bisque, 1122 13th Street, Golden, CO, 1987), $69.

This program, which has been around for a couple of years and is now in its third incarnation, has one feature not shared by any other program I have seen: the ability to zip around the sky display at will, changing azimuth with a touch of the left or right cursor-control arrow.

If your computer doesn't have an 8087 math coprocessor, however, things get a little sluggish. In this case the display can be simplified by turning off some stars with a magnitude "filter" or by eliminating unwanted groups of celestial objects. It is also possible to freeze the calculations if a thorough examination of the sky at a particular time is what you want.

The package has a relatively small object database, but it is possible to add your own — up to three thousand stars per database. It is also possible to define your own constellation connect lines if you don't like the ones that come with the package. Up to two hundred stars per constellation can be redrawn by means of a very simple and effective system. A special list of planetary data is also available, including distance from Earth in astronomical units, the apparent size in arcseconds, plus the planet's phase, solar elongation, and longitude.

The lack of a printout of rise and set times for the Sun, Moon, and other objects is a limitation. It can be remedied to some extent by watching the display for the disappearance of the object. The display can be sped up by any selected factor using the "time skip" facility, so you don't have to wait all day for the Sun to set!

— *Michael Krochmal*

Sky Travel for Macintosh, Commodore C64 and C128, Atari 800XE/XL, and Atari ST, (Deltron Limited, 155 Deer Hill Road, Lebanon, NJ 08833, Macintosh version, 1987), Commodore versions and Atari 800XE/XL, $29.95; Atari ST, $39.95; Macintosh, $49.95.

Sky Travel can be used for educational purposes or as a utility program for amateur astronomers. The database contains 1,200 stars, the Sun, Moon, planets, Halley's Comet, and over three hundred deep-sky objects.

The program works in four basic modes: sky, map, set, and chart.

Sky mode, the heart of the program, simulates the appearance of the sky and shows the apparent positions of all objects relative to the horizon (both above and below). A section of sky up to 72° across can appear on the screen at one time.

Map mode allows you to select the latitude and longitude of your viewing location by moving a cursor over the Earth. This allows you to estimate the correct coordinates if you do not know them.

Set mode lets you select the appropriate date and time of the sky you want to see. The program can display the sky from 9999 B.C. to A.D. 9999.

Chart mode allows you to make star charts of any section of the sky viewed in the sky mode.

The power and versatility of *Sky Travel* reside principally in the sky mode. Its display screen imitates the view one would see looking out a window at a section of the sky. By moving the cursor past any border of the screen, your window's view will move in that direction and reveal a new portion of the sky.

The sky mode has many helpful and interesting options. You can display several hundred deep-sky objects, constellation line diagrams and names, and planetary symbols. A clock continually updates the position of objects as time passes — it can run at various rates, even backwards. Additional sky-mode options readily locate the Moon, Sun, planets or any constellation and, if you choose, track an object as its position changes. Through these options solar and lunar eclipses and planetary transits and occultations are easily and realistically simulated.

Sky Travel is exceptionally easy to use. The speed of the program is very impressive and encourages the user to explore astronomical phenomena. You will find, however, that graphic quality varies depending on the hardware used. Although the Commodore 64 version's graphics need improvement, the Macintosh version's graphics are superb.

— *Lawrence Paul*

SUPERSTAR V2 for IBM compatibles, (picoScience, 41512 Chadbourne, Freemont, CA 94539, 1986), $129.95.

SUPERSTAR V2 is a tremendously complex package with a steep learning curve. The effort expended, however, is well worth it. This package claims to make reference to no fewer than 259,000 stars; 8,163 NGC objects; 21,500 variable stars; as well as the Messier catalog, constellations, planets, asteroids, and comets. No mean feat!

Although the program works from floppies, the amount of disk swapping can be a bit much. The program with its databases is supplied on no less than ten floppies! Unfortunately, the routine for installation to hard disk is full of bugs, so beware.

An interesting feature of *SUPERSTAR V2* is the program's ability to trace the path of celestial objects forward and backward in time, either by tracking the objects along tick marks at selected time intervals during an event or by displaying a close-up view of the objects and how they interact. *SUPERSTAR V2* can also display the angular separation of any two objects (during a planetary conjuction, say) as a function of time. These objects can be planets, the Moon, the Earth's shadow, the Sun, stars, Messier or NGC objects, asteroids, comets, and variable stars. Such a feature allows you, for example, to determine the next opportunity to photograph the asteroid 44 Nysa passing near M8.

There is a choice between Mercator and photographic projections. Mercator projection maps, of course, result in distortion near the poles. Photographic projection is "what-you-see-is-what-you-get" but takes about three times longer to generate than Mercator maps do.

The on-screen help is very comprehensive and can also be dumped to the printer. The program can run either in a menu mode or in a command-line mode. The menu mode is very easy to use and a great help for the newcomer.

This package is more expensive than the others, but considering its power, it represents an excellent value for the money.

—*Michael Krochmal*

TellStar II for IBM compatibles, (Spectrum Holobyte, Inc., 2061 Challenger Drive, Alameda, CA 94501, 1985), $29.95.

TellStar II is a good program for beginning astro-computer enthusiasts: it is easy to use, requires no previous astronomy knowledge, and is reasonably priced. It allows you to locate and identify constellations, stars, planets, the Sun, Moon, and Messier objects.

Basically, you enter your viewing location, time, and date, and the program displays the celestial objects visible at the time and place. The direction of view can be reselected (pan mode) but is restricted to the eight major compass headings. In addition, a number of calculation utilities can be performed, such as converting from right ascension and declination coordinates to altitude and azimuth coordinates and precessing from epoch 1950.

The manual suffers from the lack of an index, but at least there is a great deal of interesting data contained in the appendices. This includes the best list of Arabic star names I've ever seen.

— *Michael Krochmal*

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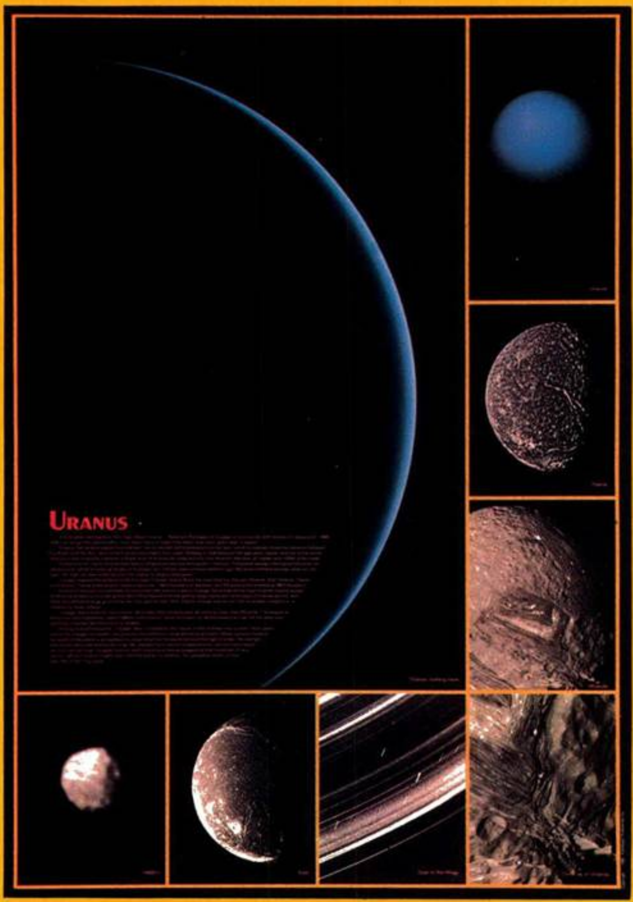

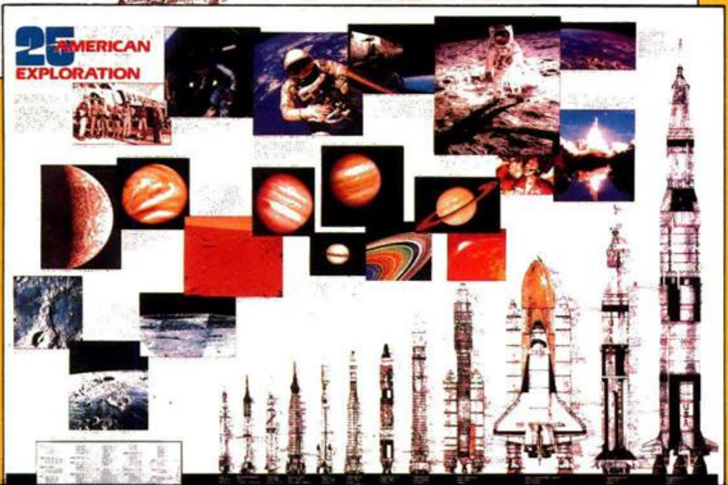

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Equipment Atlas

Build ASTRONOMY's Star Time Clock

by Irwin Sternberg

As the Sun moves across the sky, our clocks and watches keep pace. The Sun will reach its greatest elevation at noon today, just as it did yesterday and as it will tomorrow. But the same is not true of the stars. The stars that are prominent at 8 p.m. tonight will be invisible in the early evening six months from now.

Why do the stars change position when our clock says it is the same time of night? Because our clocks are based on the position of the Sun and not the positions of stars, and the Sun moves relative to the stars.

Because backyard observers are usually more interested in stellar positions than in the Sun's position, a clock that measures the time kept by the stars — sidereal time — would be a useful addition to their observing equipment.

Sidereal time runs faster than solar time by about one third of 1 percent. A sidereal day is the time it takes Earth to rotate once relative to the stars. A solar day, on the other hand, is the average time it takes Earth to rotate once relative to the Sun. Because the Sun moves east relative to the stars, after one sidereal day Earth must rotate through a small additional angle to complete one solar day.

The Sun takes about 365.25 days to make one complete circuit through the stars, so each day it moves approximately one degree. Earth rotates through that extra degree in about four minutes, which makes a solar day four minutes longer than a sidereal day. Thus, 24 hours of sidereal time elapse in 23 hours and 56 minutes of solar time.

Clocks that run at a sidereal rate are now a reality. Although sidereal timepieces are commercially available, they are not cheap. But, for a total cost in materials of about $25, you can easily modify an existing digital clock so that it keeps sidereal time. The only electronics expertise you'll need to build the modification is the ability to solder.

With a sidereal clock you will be better equipped to plan observing sessions and to identify objects you come across while scanning the sky. The position of an object in the sky is defined by the object's right ascension and declination coordinates, and right ascension is directly related to sidereal time.

An object lies on your local meridian — the circle on the sky that passes directly overhead and through the north and south points on your horizon — when the sidereal time is equal to the right ascension of the object. Because an object is highest in the sky when it lies on the meridian, you can plan an observing session around objects with right ascensions fairly close to local sidereal time.

For instance, all objects with a right ascension of 5 hours and 30 minutes (5h30m) are on your meridian at 5:30 sidereal time. Furthermore, objects with a right ascension of 4h30m were on your meridian one sidereal hour earlier. One sidereal hour after 5:30 objects with a right ascension of 6h30m will be on your meridian.

To make a clock that reads sidereal time, all you need to do is speed up a normal clock by the right amount. The *Astronomical Almanac* lists this factor as 1.000273790934, accurate to twelve decimal places. To make our clock conversion simpler, we will approximate the ratio of solar to sidereal time with the ratio 2,930/2,922. This introduces an error of only six millionths of 1 percent.

Getting the Right Clock

The sidereal clock I made is nothing more than an ordinary electric digital clock modified to run at a slightly faster rate. I didn't have a digital clock of my own to modify, so I bought a Micronta LED Digital Alarm Clock from Radio Shack (Catalog Number 63-755). Whether you choose to modify your own clock or buy a new one, the clock must have the following features:

- It must be able to display time in a 24-hour format.
- It must operate at 115 volts AC, 60 hertz.
- It must have a 50/60-hertz select option.

The 60-hertz line frequency is an excellent time reference for the clock because it is temperature independent. This means the clock can be kept outdoors all year round without being affected by the frequency drift often associated with crystal driven clocks.

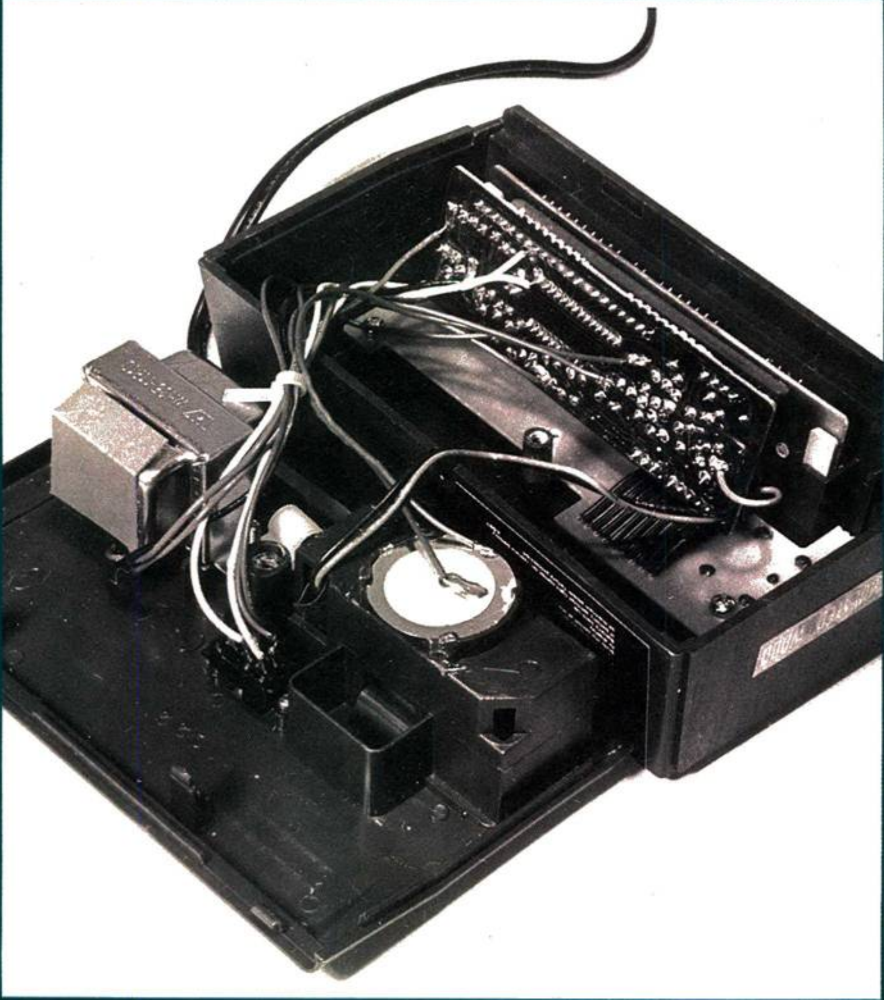
The 50/60-hertz select option is the key to our modification. When set at 50 hertz, the clock advances six minutes for every five minutes of elapsed time. In the modification we take advantage of this feature by electronically switching between the two frequencies to increase the clock rate by a factor of 2,930/2,922.

The 50-hertz option is included by some manufacturers to accommodate the European line frequency of 50 hertz. However, even if the clock is capable of running at 50 hertz, the option is usually not obvious on models sold in the United States. For instance, the clock I bought does not mention the 50-hertz feature anywhere on the box it came in or on the clock itself. Only by carefully reading the instruction manual did I find out that the clock can operate at 50 hertz. A specific model will have the 50/60-hertz select option if the manual mentions a European or Australian version.

In addition to the clock you will need about $10 worth of materials to build the modification. These components are itemized in the parts list on page 45. The modification consists of adding four integrated circuits (ICs), four capacitors, and two resistors to the existing clock circuitry. The existing circuitry remains physically untouched. When the modification is finished, it is wired to four easily accessible input points on the clock's circuit board.

Building the Modification

Time is monitored by the integrated circuits U1, U2, and U3. These integrated circuits count 2,922 60-hertz clock pulses from the existing clock circuitry. Between the counts of 2,880 and 2,920 the clock is switched from the 60-hertz to 50-hertz mode. During this 40-pulse interval the clock will actually "count" 48 pulses.

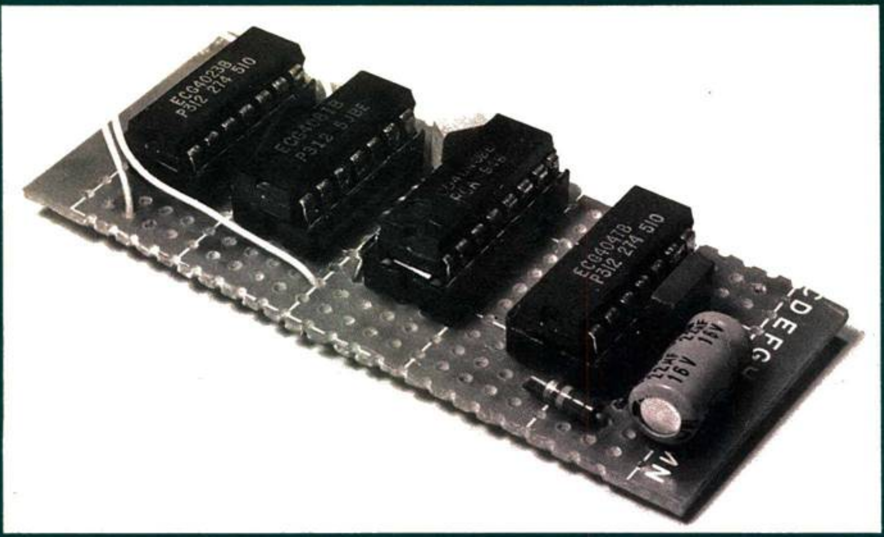


Above: Most of the components for a do-it-yourself sidereal clock can be found at Radio Shack and other electronics supply stores. All photos by Tom Hunt.

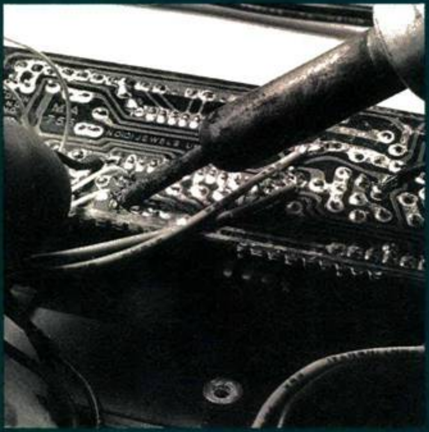
Left: A simple modification wired to four points of a digital clock's circuitry will turn the clock into a sidereal clock.

Parts List for the Modification

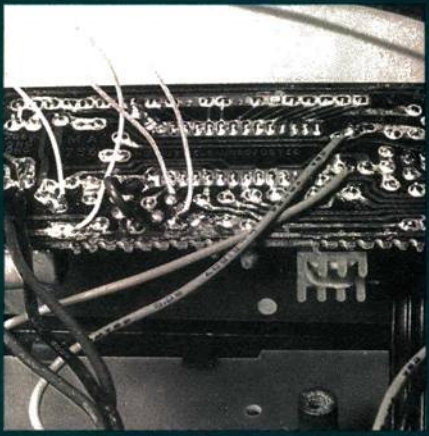
1	CD4040B Integrated Circuit
1	CD4023B Integrated Circuit
1	CD4081B Integrated Circuit
1	CD4047B Integrated Circuit
1	100K-Ohm Resistor
1	22K-Ohm Resistor
1	22-Microfarad Capacitor
1	0.1-Microfarad Capacitor
1	0.01-Microfarad Capacitor
1	0.001-Microfarad Capacitor
1	1.2'' x 2.5'' piece of 0.100'' x 0.100'' Vectorboard
1	16-Pin Socket
3	14-Pin Sockets

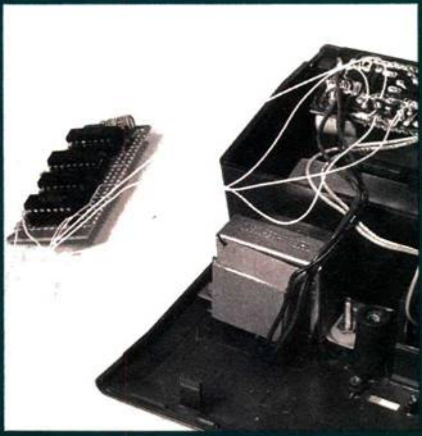


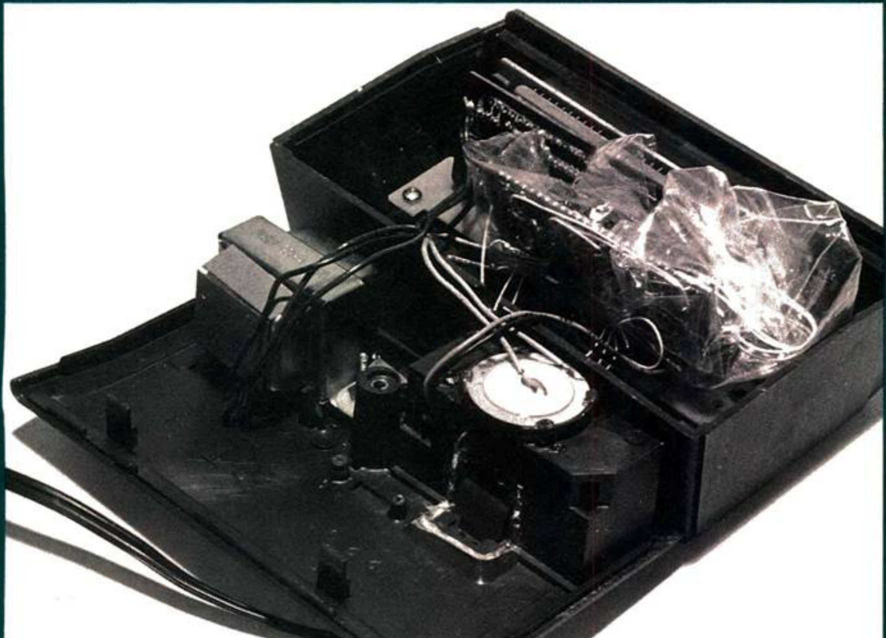
Left: The sidereal clock modification circuit will look like this when it is finished. The integrated circuits control the clock so it runs at the sidereal rate, a factor of just 2,930/2,922 faster than a normal clock. All the electrical connections are made on the underside of the Vectorboard.



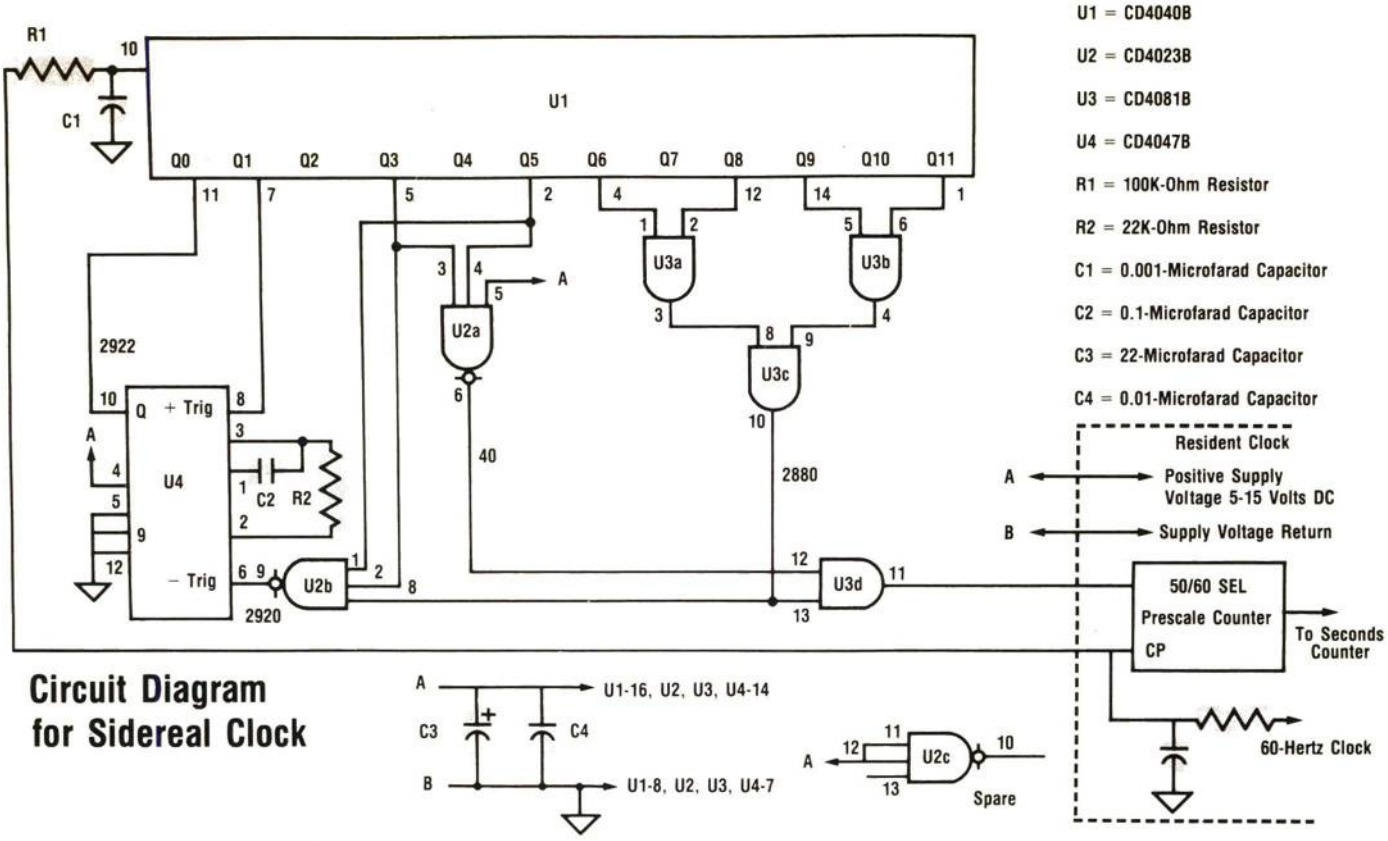
Above: Use a small-tipped soldering iron to solder the connections. Heat both the socket pin and the connecting wire and then touch a small amount of solder to the connection. A good connection will appear shiny, a poor connection battleship gray and dull.







Once you have finished building the modification, you have to wire it to four points in the existing clock circuitry. These points are the 60-hertz clock, the 50/60-hertz SELECT, the chip energizing voltage, and the voltage return. If you use the same Micronta clock model I did, you can see from the photo (above left) where the connections are made; otherwise consult the clock schematic. Once wired, enclose the completed circuit board in a small plastic bag and place it inside the clock.



U1 = CD4040B

U2 = CD4023B

U3 = CD4081B

U4 = CD4047B

R1 = 100K-Ohm Resistor

R2 = 22K-Ohm Resistor

C1 = 0.001-Microfarad Capacitor

C2 = 0.1-Microfarad Capacitor

C3 = 22-Microfarad Capacitor

C4 = 0.01-Microfarad Capacitor

Circuit Diagram for Sidereal Clock

Thus the indicated time to elapsed time ratio is 2,930/2,922. Integrated circuit U4 clears all the counter registers after 2,922 clock pulses and the cycle then repeats.

Mount the sockets onto a 1.2″ by 2.5″ piece of 0.100″ by 0.100″ Vectorboard. There are two advantages to using sockets to hold the ICs. Soldering directly to the pins of an integrated circuit exposes the IC to high temperatures, and ICs are heat sensitive. Second, if you make a wiring error, the IC will get zapped. Soldering to the socket pins allows you to replace a damaged IC without having to rewire all the connections.

The circuit diagram above shows which pins on which ICs have to be connected. To determine which pin is which, find the end of the IC with a notch in it. Holding the IC so the pins point up and the notch is toward you, pin 1 is the nearest pin on the left. Pin 2 is the one immediately behind that one and the pin numbers keep increasing up the left side of the IC. When you reach the last pin on the left side of the IC, the next sequential pin number is directly opposite it. Then continue counting pins on the right side until you reach the highest numbered pin, which is the nearest pin on the right as you look at the IC.

Solder the connections on the underside of the board with a hot soldering iron with a small tip. Wrap the wire you'll use to the make the connection around the socket pin and heat both with the soldering iron. Once they are hot enough, touch just enough solder to the connection to flow over the connection. You don't want a big blob.

Once you have built up the circuit, you must wire the modification to four points in the existing clock circuitry. These points are the 60-hertz clock (pin 27 on the LM8560 in the Micronta clock), the 50/60-hertz SELECT (pin 25), the chip energizing voltage (+5 to +15 volts DC), and the voltage return. These points can be found by referring to the clock schematic or the clock chip data sheet. If you use the same Micronta clock model I did, you can look at the photo on page 46 to determine the correct points.

In the Micronta clock model the 50/60-hertz SELECT is active high (logic 1) for 50 hertz and active low (logic 0) for 60 hertz. If you use a clock with the opposite convention, connect the spare gate U2c to invert the signal from U3d.

The last point to keep in mind is the susceptibility of integrated circuits to electric charges. Do not insert or remove the chips from their sockets while the unit is powered. Also avoid finger contact with conductive surfaces: the ICs can be ruined from the static charge.

Setting the Time

Once you have built the clock, all you have left to do is synchronize it with the sky. Because the sky is a sidereal clock in its own right, you could set your clock to coincide with a star's position.

To set your clock accurately, you'll need some help. If you own a computer or have access to one, you can set the sidereal clock with a sidereal time computer program. (See "What Time Is It?" by Richard C. Walter, Equipment Atlas, February 1987.) Otherwise you will need to calculate the sidereal time for your specific location by comparing your local sky to the sky in Greenwich, England. To do this, you will need to know your longitude and have a table that gives the sidereal time in Greenwich.

Your longitude can usually be found in any of several major atlases, in the *World Almanac*, and on topographic maps and some road maps. Convert the longitude (expressed in decimal degrees) to a time by dividing by 15 and express the result in hours and minutes.

For example, if you live at longitude 100° west, divide 100 by 15 to get 6.67 and then multiply the decimal part by 60 to get the minutes. The result — 6 hours and 40 minutes — is the length of time it will take a star currently on the meridian in Greenwich to reach your meridian.

Now all you need to know is the sidereal time in Greenwich. The *Astronomical Almanac* gives these values for 0 hours universal time. If you set your clock at this time (19:00 EST, 18:00 CST, 17:00 MST, and 16:00 PST the day before), your local sidereal time is approximately the sidereal time at Greenwich minus the time difference calculated above. If the subtraction yields a negative number, simply add 24 to get your local sidereal time.

The finished clock makes a great conversation piece. But its real value will be out under the stars with your telescope, where the clock will serve as a handy reference, keeping perfect sidereal time throughout the year.

Irwin Sternberg is a systems engineer employed by Harris Corporation in Syosset, New York.

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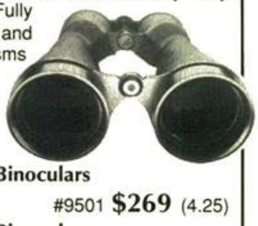

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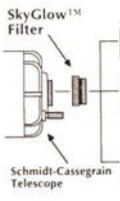

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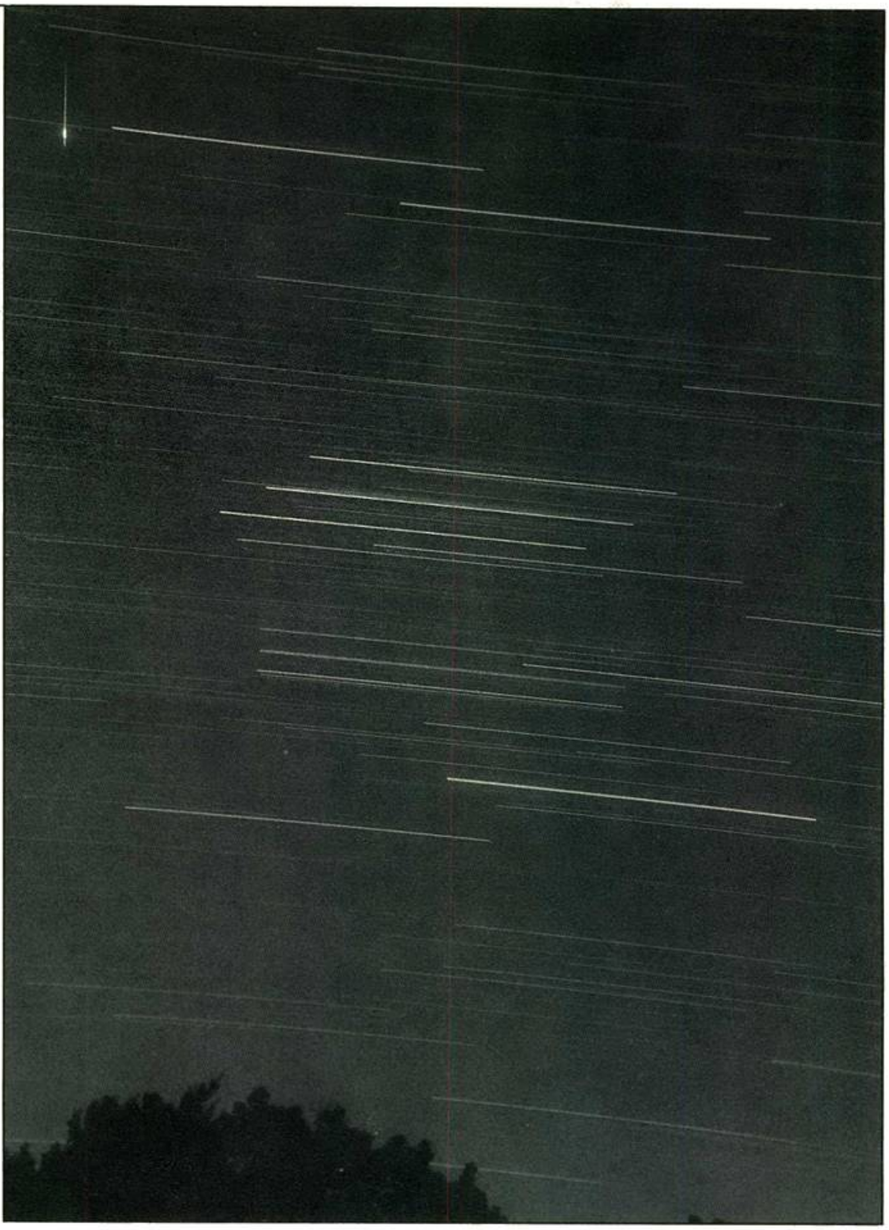
Capturing the Conjunction of Jupiter and Venus

by Robert Burnham



The Wanderers

Even if you merely glance at the evening sky this month, you can't miss two very bright "stars" close together in the southwest. These are **Venus** (the brighter at magnitude −4.2) and **Jupiter** (at magnitude −2.1).

On March 6, Venus is just 2-1/2° (five Moon-diameters) away from Jupiter. If clouds interfere on that date, don't worry. These two objects will dominate the evening sky all month. Binoculars show both planets in the same field, but naked-eye views of the planets' day-to-day movement are more spectacular because objects silhouetted in the foreground will make the scene three dimensional.

This is also a first-class photo opportunity. Get out the tripod and load your camera with fast film (slides are preferable). Then choose a lens for the kind of picture you want. Telephotos will catch Venus and Jupiter when the planets are close together, but Jupiter's downward slide as the month progresses will soon carry the planet out of the field of view. For a truly scenic shot, therefore, use a normal or wide-angle lens and include some foreground objects.

On or before March 1, start going out every clear night and pointing the camera as accurately as you can in the same direction, using a prominent tree or utility pole as a guide. Then set the lens to its widest aperture (lowest f/number) and take a series of pictures lasting 1/2, 1, 2, 5, and 10 seconds. "Bracketing" your exposures guarantees that at least one frame in each night's shooting will capture the feeling you want.

When the photos are developed, arrange the best ones in order by date. The result should look like a set of movie frames showing planetary motion — and will surely impress anyone you show it to.

Jupiter sets about 9 p.m.; Venus around 10:30. Thereafter the sky will be free of naked-eye planets until **Saturn** rises at 1:30 or 2 a.m., followed roughly an hour and a half later by **Mars**. But viewing these morning planets is better if you get up an hour before sunrise.

Go out where you have a clear southeastern view. As the sky brightens and the eastern horizon begins to color, Saturn will be about 20° high in the southeast. (See the diagram on page 50.) Nestled among the evening constellations of summer, Saturn shines ivory-white at magnitude 0.5. Mars lies to its lower left and looks perceptibly redder; it is almost as bright as Saturn.

On March 1, and continuing for about three weeks, **Mercury** can be seen close to the horizon well to the left of Mars. Mercury is highest on the 1st but becomes too low to be seen by about the 20th; greatest elongation is on March 8. Mercury looks reddish white and shines at 0.2 magnitude.

At Full Moon on March 3, a very shallow **partial lunar eclipse** will be visible from Alaska and Hawaii shortly before moonset. The Moon spends 14 minutes slipping through the northern edge of the Earth's shadow; mid-eclipse occurs at 6:13 a.m. (Hawaii time) or 7:13 a.m. (Alaska time). The penumbral shadow will darken

Above: An Orionid meteor zipping past Betelgeuse (upper left) flares before vanishing. Photo taken October 21, 1987, by John Gianforte with a 50mm lens at f/4.0, Tri-X 800 film, and a 37-minute exposure.

Opposite page: The greenish white light emitted by atomic oxygen gives this auroral ray band its color. A. W. Steinbrecher used a 50mm lens at f/1.4, Ektachrome 400 film, and a 12-second exposure.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

March Night Sky

Full Moon
March 3
11:01 a.m. EST

Last Quarter
March 11
5:56 a.m. EST

New Moon
March 17
9:02 p.m. EST

First Quarter
March 24
11:41 p.m. EST

1st The Moon is farthest from Earth (the first of two times this month) at 6:52 a.m. EST: 252,433 miles (406,251 kilometers). Mercury is at its best visibility (highest elevation) in the morning sky and will remain in sight until about the 20th.

3rd Full Moon occurs at 11:01 a.m. EST in Leo. There is a partial eclipse of the Moon visible primarily from Asia but also from Alaska and Hawaii (see text).

6th Venus passes 2°24″ north of Jupiter at 3:25 p.m. EST

7th Mars passes 1°22″ south of Neptune.

8th This morning Mercury is at greatest elongation west of the Sun (though highest elevation and best visibility were a week ago).

11th Last Quarter Moon is at 5:56 a.m. EST in Ophiuchus.

13th The Moon lies to the lower left of Saturn and Mars in the morning sky today (see diagram below).

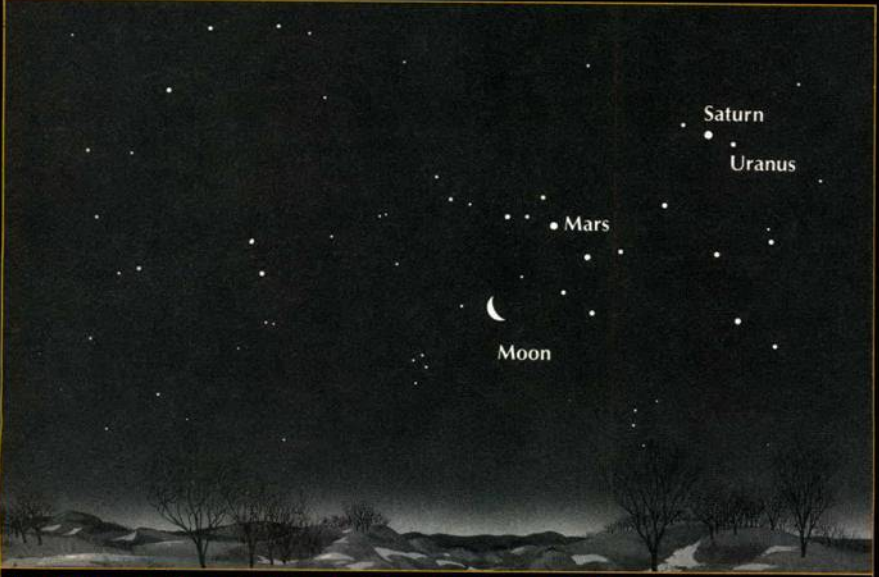
16th The Moon is closest to Earth at 3:28 p.m. EST: 223,393 miles (359,517 kilometers). It also passes just south of Mercury, covering the planet for viewers in Antarctica, Indonesia, and most of Australia.

17th The Moon is New at 9:02 p.m. EST in Pisces; a total eclipse is visible in Indonesia, the Philippines, and the northwestern Pacific Ocean (see text).

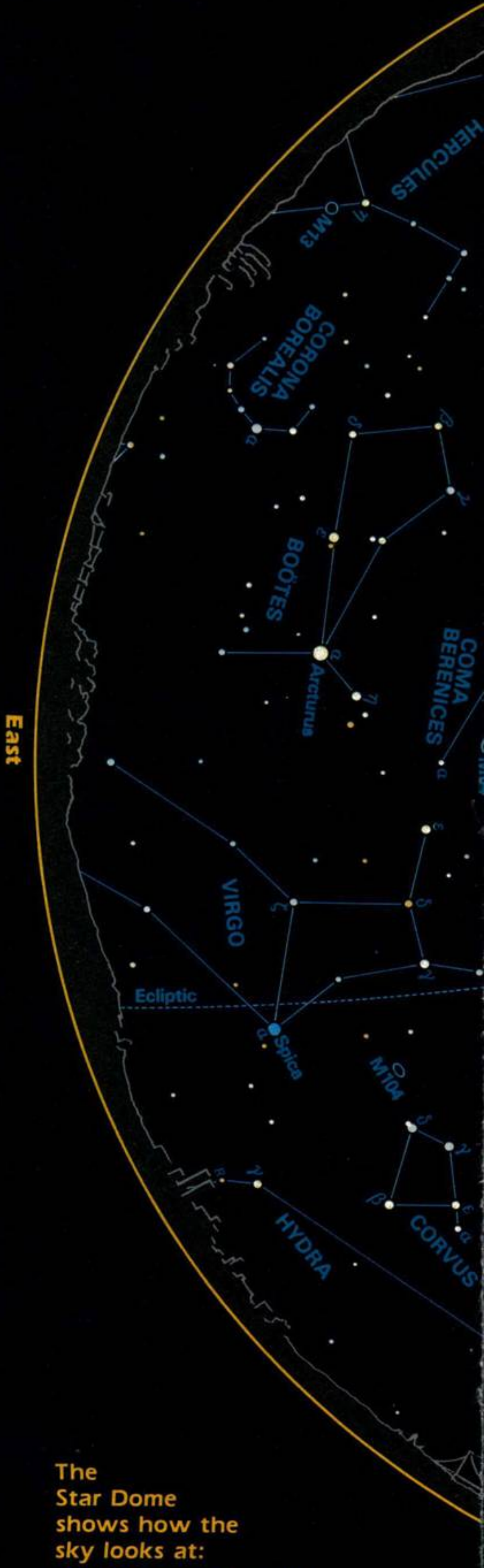
20th The Moon lies above and between Jupiter and Venus in the evening sky tonight.

24th First Quarter Moon occurs at 11:41 p.m. EST in Gemini.

28th The Moon is farthest from Earth again at 7:28 p.m. EST: 251,949 miles (405,473 kilometers).

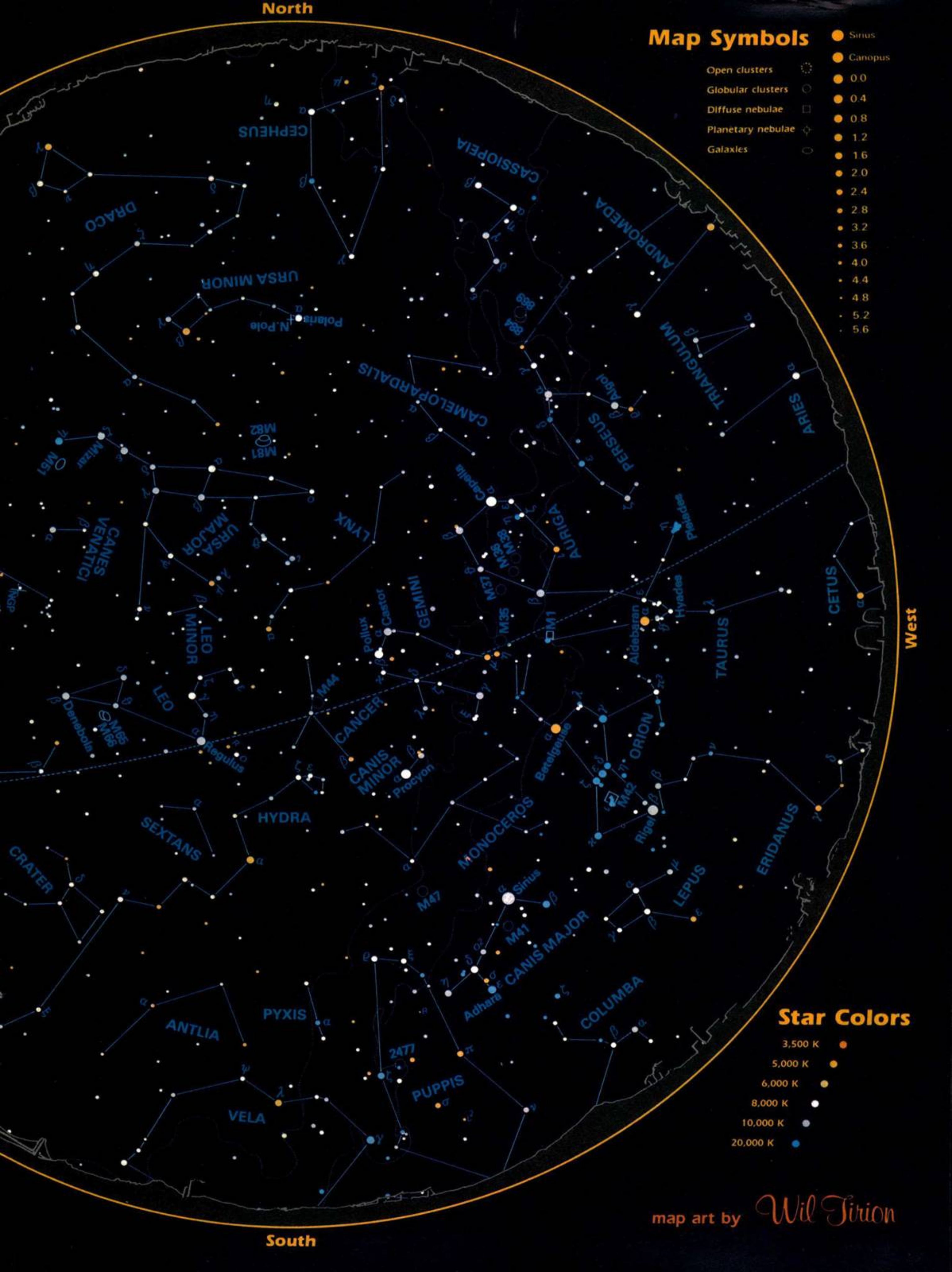


Looking southeast, March 13, morning twilight



The Star Dome shows how the sky looks at:

10:30 p.m. on March 1
9:30 p.m. on March 15
8:30 p.m. on March 31


North
Map Symbols
Sirius
Canopus
Open clusters
Globular clusters
Diffuse nebulae
Planetary nebulae
Galaxies
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
CEPHEUS
CASSIOPEIA
DRACO
ANDROMEDA
URSA MINOR
Polaris
N.Pole
869
884
TRIANGULUM
CAMELOPARDALIS
Algol
PERSEUS
ARIES
M82
M81
M51
Mizar
Capella
Pleiades
AURIGA
CANES VENATICI
URSA MAJOR
LYNX
M38
M36
M37
M35
M1
CETUS
GEMINI
Castor
Pollux
Hyades
Aldebaran
TAURUS
West
LEO MINOR
M44
LEO
Denebola
M65
M66
CANCER
Regulus
Betelgeuse
ORION
M42
CANIS MINOR
Procyon
HYDRA
SEXTANS
MONOCEROS
Rigel
ERIDANUS
CRATER
M47
Sirius
LEPUS
M41
CANIS MAJOR
Adhara
PYXIS
COLUMBA
ANTLIA
2477
PUPPIS
VELA
Star Colors
3,500 K
5,000 K
6,000 K
8,000 K
10,000 K
20,000 K
map art by Wil Tirion
South

Opposite page: The crescent Moon and Venus set above Mount Rainier in the Cascade Mountains of Washington in July 1981. Photo by Roy E. Gephart, taken with a 100mm f/8 telephoto on Kodachrome 64 film and a 1-second exposure.

the southern limb of the Moon and will slightly dim the rest of the Moon.

A total solar eclipse occurs on March 17, but it cannot be seen from North America except as a partial eclipse visible just before sunset for viewers in Alaska, the Yukon, and the westernmost Hawaiian islands.

The Starry Sky

The stars tonight naturally fall into two groups: those in the west belong to the bright constellations of winter and those in the darker region to the east belong to spring. Winter's star-figures look good even from an urban backyard, but because the spring constellations can't compete with manmade lighting, you'll need the darker skies of the country if you want to learn these constellations.

Orion the Hunter is leaning over in the southwest, his three-starred belt level with the horizon, while a line from ruddy Betelgeuse in one shoulder runs straight down to blue-white Rigel in his knee. Orion has almost conquered his foe, the snorting Bull **Taurus** with its triangular face in the Hyades and its horns jabbing upward at **Gemini** the Twins and **Auriga** the Charioteer. Auriga uses one tip of Taurus' horns, bright Capella ("the little goat"), the Kids (ε, ζ, and η), and a couple other stars to make a pentagon. To Auriga's left the Twins stand upright, their heads at 1st-magnitude Castor and Pollux and their feet toward Betelgeuse.

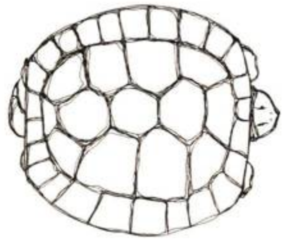
Baying at Orion's heels is the Greater Dog **Canis Major**, now in full dash with its eye, Sirius, gleaming. Behind Canis Major part of the great ship *Argo*, divided into Sails (**Vela**) and Stern (**Puppis**), drifts backward with the Milky Way.

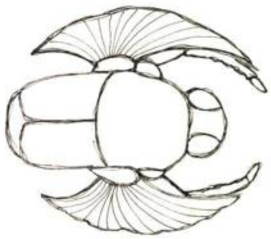
Directly above Sirius is Procyon, the eye of **Canis Minor** the Lesser Dog, and above that is **Cancer** the Crab, one of the zodiac's dimmest figures (see Skylore). Cancer is halfway between Gemini and the next member of the zodiac, **Leo** the Lion with its brightest star Regulus almost exactly on the ecliptic. The Lion's head and mane are made up of a backward "?" and its hindquarters of a right triangle. The constellation always appears wider than the map leads you to think. Above Leo is diminutive **Leo Minor**.

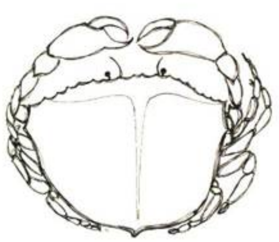
Between Leo proper and Vela, the Water Snake **Hydra** makes a home. Its head is a small oblong due south of Cancer while its body zigzags dimly eastward to the horizon. The Crow and Cup (**Corvus** and **Crater**) perch on one of Hydra's coils. Though placed lower, Corvus is easier to trace because its stars are about a magnitude brighter than those of Crater.

Let's now turn and face due north. **Cepheus** the King lies below the pole star Polaris, part of the Lesser Bear **Ursa Minor**. City dwellers can spot Polaris easily enough and perhaps even Beta (β), called Kochab, but the rest of this figure is hard to see. Cepheus' Queen, **Cassiopeia**, is an angular group to the lower left of Polaris. Above her the Giraffe **Camelopardalis** and the **Lynx** are dim figures for rural viewing only — as is the sinister figure of **Draco**, curled to the lower right of Polaris.

But over the pole is one star-figure almost everyone can identify — the Big Dipper. The seven brightest stars in **Ursa Major** the Great Bear form the body and tail of the creature; its nose extends left to Lynx and its paws run toward Leo. The two end stars in the Dipper's bowl indicate the direction to Polaris and are thus known as the Pointers. The Dipper's handle is also an indicator. If you follow the handle's curve out toward a yellowish red star rising in the northeast, you have reached Arcturus, the main luminary of **Bootes** the Herdsman and the guardian of spring flocks.







Skylore

If there was ever a prize for celestial inconspicuousness, Cancer ought to win it. This dim figure, which most stargazers can locate only by looking halfway between Regulus and Castor, contains no star brighter than 4th magnitude, and from an urban backyard the constellation is rarely visible. Circumstances, however, put Cancer into the zodiac's magic circle and thereby gave Cancer what it could never earn.

Early Akkadian records call Cancer the "Sun of the south," but Cancer has not been the location of the winter solstice since about 13,000 B.C., and it's unlikely any memory from that time survived. In Babylon and Egypt, Cancer was originally figured as a tortoise. Later the Egyptians changed the constellation to a scarab beetle, and the beetle's similarity to a crab is obvious. The Egyptians envisioned Cancer pushing the Sun along the zodiac, much as a scarab rolls a ball of dung. The Arabs saw it as an extension of Leo and called it "the Lion's mouth."

When Hipparchus was compiling his star catalog in the second century B.C., Cancer marked the summer solstice. Therefore the place on Earth where the Sun stood overhead at the summer solstice was called the Tropic of Cancer and its companion latitude for winter was the Tropic of Capricorn(us). Precession's slow march has now shifted the solstice to between Gemini and Taurus, but the time-hallowed geographical names continue.

The Greeks invented many legends about these stars — the one most often quoted is Hercules' fight with the Lernean hydra (see Skylore, April 1987). In that epic battle Hera sent the giant crab Cancer to harass Hercules because he was the offspring of her errant husband Zeus and a mortal woman. But Hercules, distracted momentarily by the crab, crushed it underfoot and went on to kill the hydra. Hera then raised the hapless crab into the heavens.

Another Greek legend harks back to when the gods and the giants were warring. Dionysus and Silenus were combatants for the Olympians and rode into battle on two asses. These creatures brayed so loudly they helped frighten the giants and contributed to the gods' victory. In recognition they were put in the sky in Cancer, where they are the two eastern stars in the crab's body.

The two asses explain why the star cluster (M44) bears the nickname Praesepe. This word is Latin for "manger" and the cluster is a never-ending pile of hay — an appropriate reward for the valiant beasts. The cluster is also called the Beehive, perhaps because the stars of the cluster appear to swarm gently when seen through inferior optics.

Aratos (and later Pliny) wrote that Praesepe's visibility offers clues for predicting the weather: if the cluster can be seen by the naked eye, fair days will surely follow. Old weather sayings are notorious for stretching a kernel of truth far beyond its elastic limit. But it is true that the slightest amount of haze — from oncoming cirrus, perhaps — will obliterate the Beehive.

So why not give the old idea a try this month: check the cluster's visibility and log the weather during the week to follow. How well does Aratos compare to the weatherman on the nightly news?

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ASTROPHOTO OF THE MONTH

Open Cluster NGC 2264 and associated nebulosity in Monoceros. The "cone" nebula (dark protrusion) is to the left and bright star S Monocerotis is to the right; north is to right. This nebulosity has very low surface brightness, and reliable visual sightings of the cone nebula are not yet reported; try a LUMICON H-Beta filter or a LUMICON Oxygen-III Filter. NGC 2264 is best photographed with a LUMICON DEEP-SKY Filter. Photo by Bill Sorrells, 16" f/5, hyper 2415 film, 40 minutes using a LUMICON 2" EASY-GUIDER™

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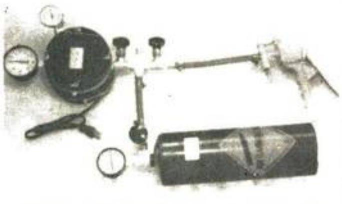

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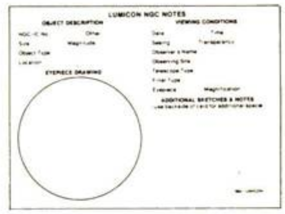
LUMICON NGC NOTES
OBJECT DESCRIPTION
VIEWING CONDITIONS
EYEPIECE DRAWING
ADDITIONAL SKETCHES & NOTES

NGC NOTES

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All foreign orders add 6% ($8 minimum). California residents add 6% tax. Prices subject to change w/o notice. Set Meade and LUMICON Catalogues $4. **LUMICON, 2111 Research Dr., #5, Livermore, CA 94550.** Call **(415) 447-9570** for information & orders. Store Hours: M-F 9am-5pm; Sat 11am-3pm. All telescopes shipped F.O.B. Livermore.

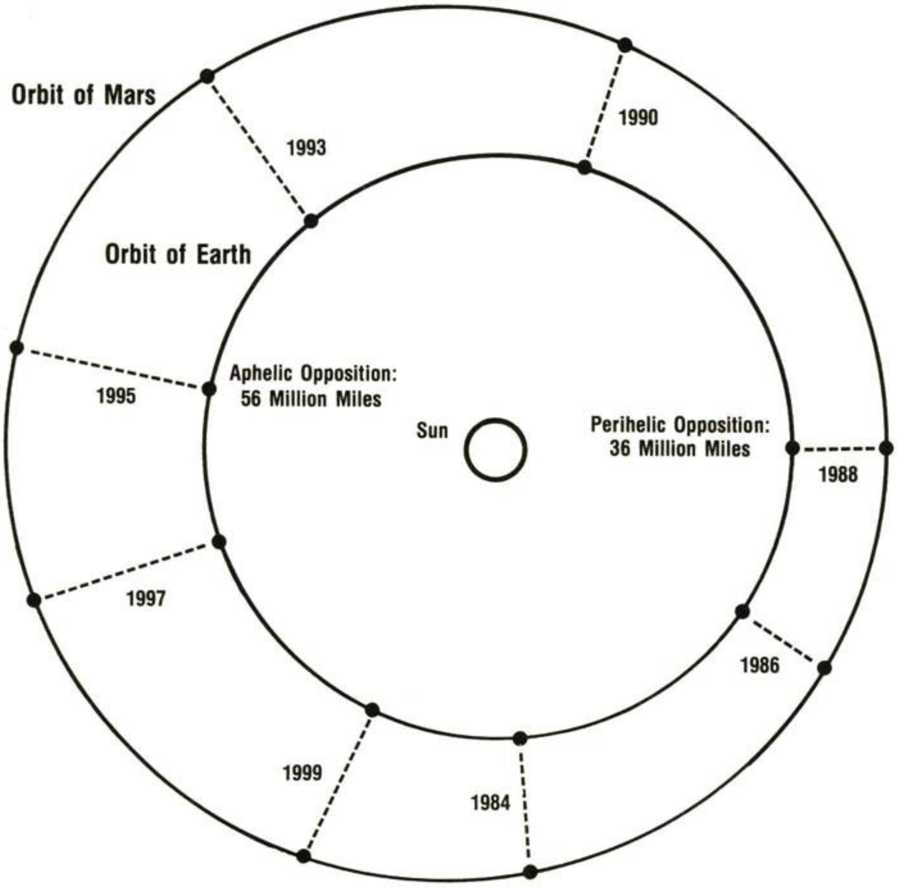
Gazer's Gazette

1988: A Great Year for Mars

By Jeff Beish and Donald C. Parker

During 1988 Mars will come closer to Earth than it has in the last seventeen years, and every astronomy enthusiast will have the opportunity to see and enjoy Mars. We want to heighten your awareness of Mars in the coming year and, by explaining what kinds of observations are possible and how you could be making such observations, enlist your support as a Mars observer.

What we as representatives of the Association of Lunar and Planetary Observers (ALPO) are asking you to do — sketch Mars from your backyard — may seem old-fashioned and unscientific compared to the accomplishments of the *Mariner* and *Viking* missions to Mars. These missions mapped geological features and monitored meteorological phenomena of the planet from orbit. But the spacecraft are no longer in operation. Until the next missions reach Mars, everything we learn about Martian phenomena will come from terrestrial telescopes — and amateur planetary observers.


Oppositions of Mars

In 1988 Mars comes to opposition only 35 million miles from Earth. We will have to wait seventeen years for another chance to observe the Red Planet so well.

Despite centuries of surveillance by Earth-bound astronomers armed with powerful telescopes and two decades of close scrutiny by orbiting spacecraft, Mars remains an object of mystery and intrigue. Important scientific questions about the Red Planet remain unanswered. You can help us answer them.

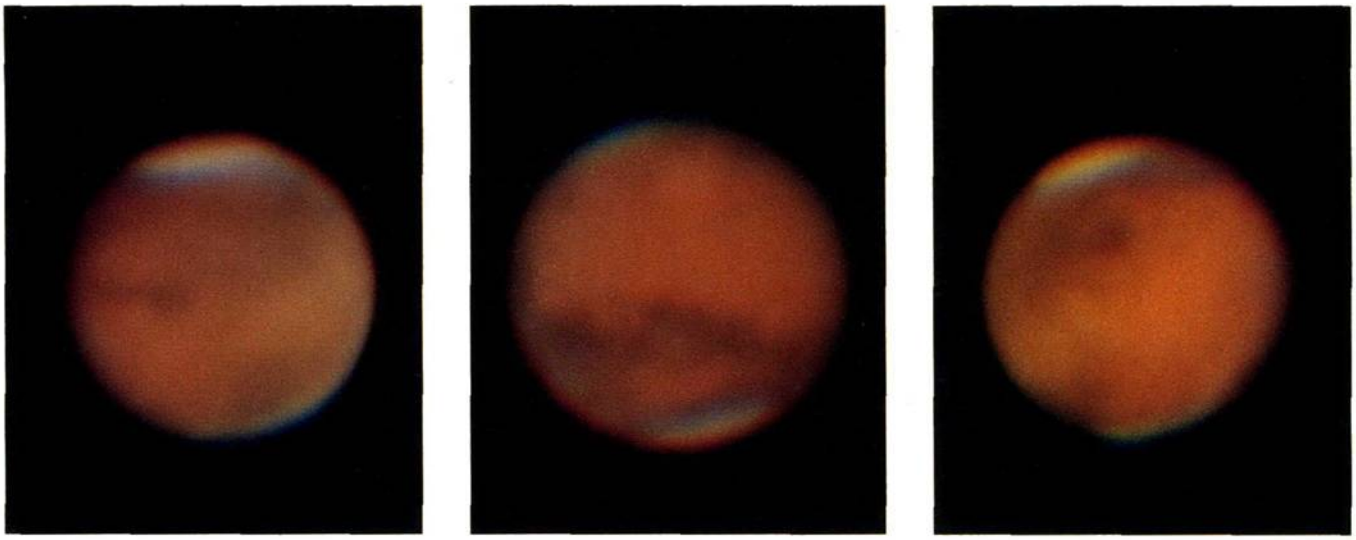
It falls to the visual observer armed with a 4-inch or larger telescope to keep an eye on Mars and to report observations to the astronomical community. What's required is enthusiasm, persistence, dedication, and care.

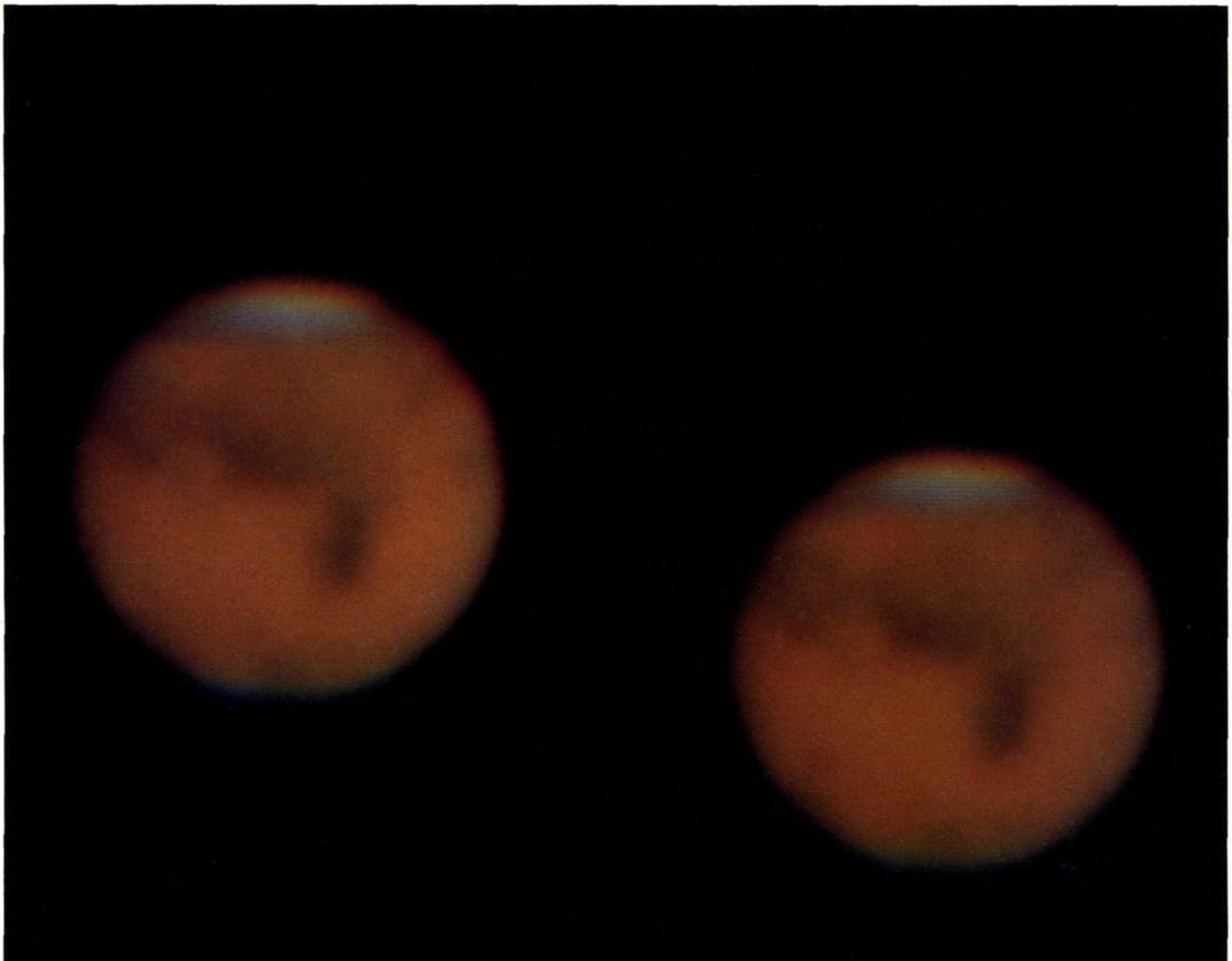
Keeping a Watch on Mars

Viewing with the human eye is the most sensitive way to record features of planets. The human eye and brain readily detect subtle patterns of light, shade, and color that even the best modern films miss. Because the eye records planetary features during successive brief moments of atmospheric stability, an observer with a small telescope can build up a detailed composite image of the planet in his mind. Transferred to paper as a sketch, that subtle detail is preserved for later study. If you have a 4- to 10-inch telescope, we would like you to sketch Mars for us.

Mars is the only planet with a surface that can be plainly seen and charted from Earth. Since spacecraft have photographed Mars, we know the gray-green features observers see on the Martian disk are a variety of structures, and the appearance and borders of these structures are modified seasonally or over the years by windblown dust. Visual observers can also document the shrinking of the southern polar cap, as Martian spring turns to summer and the snows thaw. During 1988 observers will write another chapter in the observational history of changing Martian features.

For visual observers the Martian atmosphere offers more variety than any other





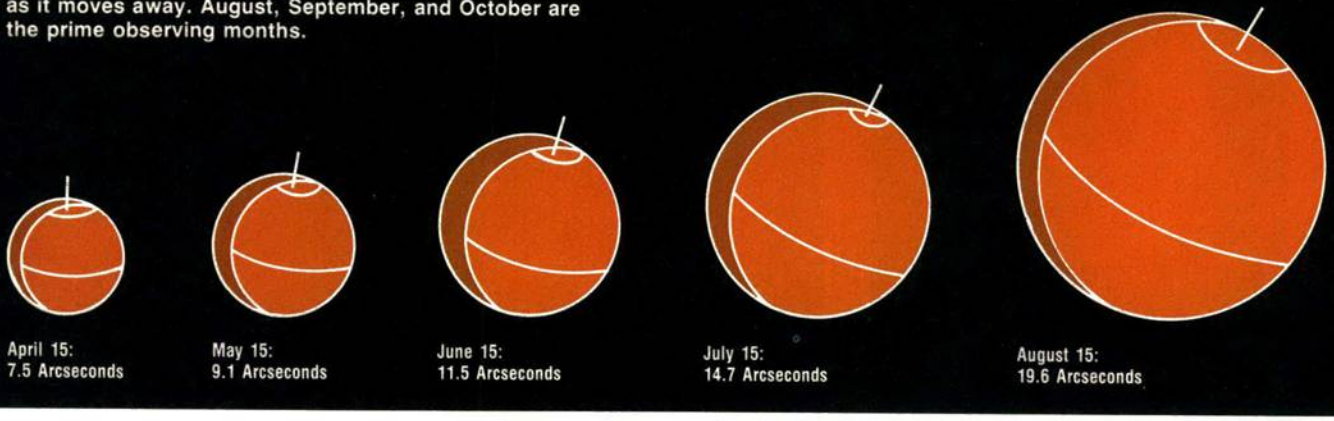
These photos of Mars show features you can see with a small, high-quality telescope. South is at top in all photos.

Large photo: In this double exposure of Mars the large, dark feature called Syrtis Major is nearly central on the planet's disk.

Top row. Left: Margaritifer Sinus is shaped like the bowl and stem of a pipe. Center: Mare Cimmerium is central on the disk. Right: Like a giant eye, Solis Lacus dominates the southern half of the Martian disk. Photos by Donald C. Parker, taken during the 1986 opposition.

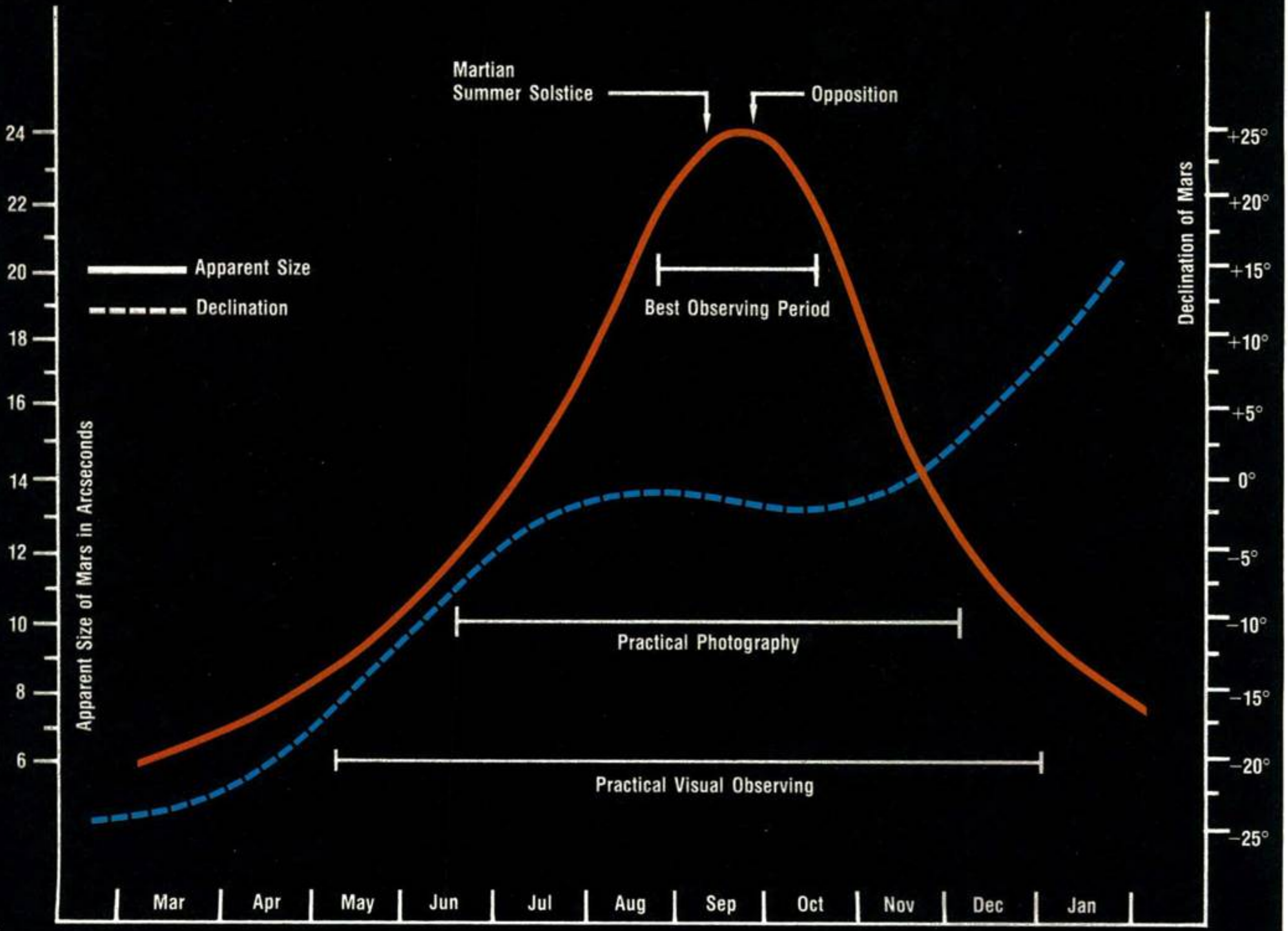
Mars Approaches and Recedes

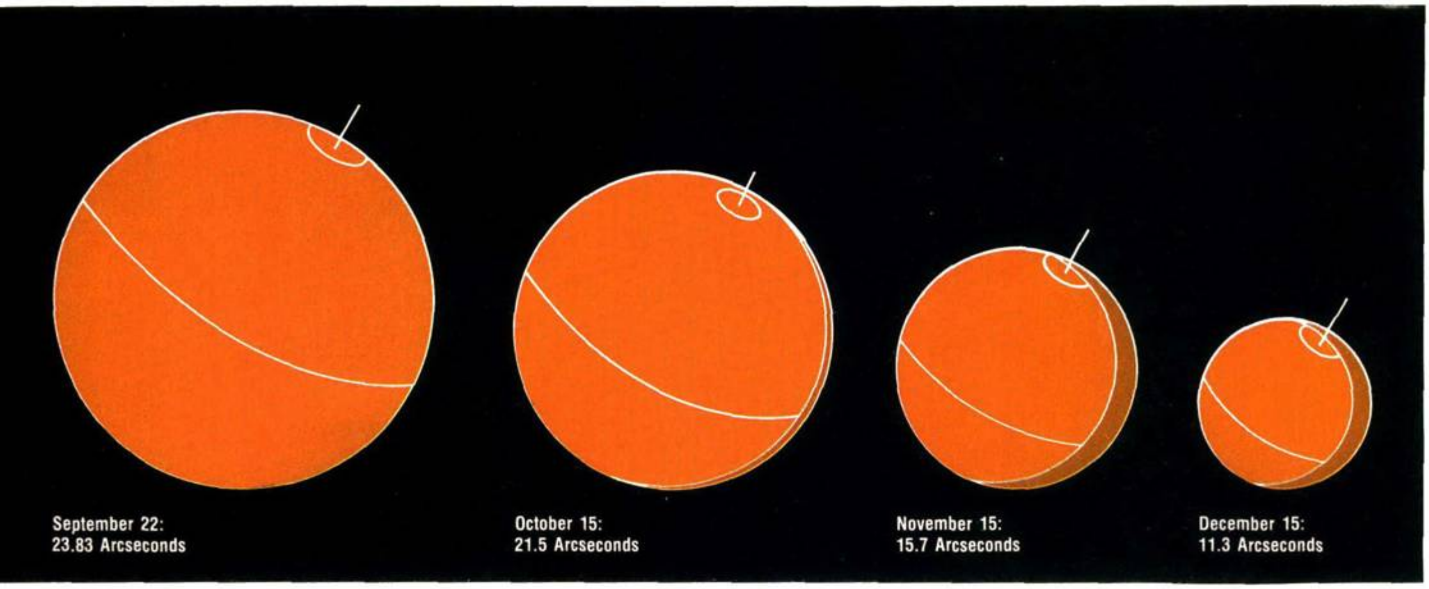
As Mars approaches Earth, it will swell from a tiny disk in April to maximum size on September 22, and then shrink as it moves away. August, September, and October are the prime observing months.


April 15:
7.5 Arcseconds
May 15:
9.1 Arcseconds
June 15:
11.5 Arcseconds
July 15:
14.7 Arcseconds
August 15:
19.6 Arcseconds

When to Observe Mars in 1988

Mars grows rapidly in size before opposition and then just as rapidly shrinks. The best visual observing occurs when Mars is larger than 20 arcseconds, but observations are practical whenever Mars is larger than 6 arcseconds.




September 22:
23.83 Arcseconds
October 15:
21.5 Arcseconds
November 15:
15.7 Arcseconds
December 15:
11.3 Arcseconds

Martian feature. In 1988 you can watch white clouds form downwind from the big volcanoes, track the yellow dust storms as they build over the plains, and monitor the blue hazes in the atmosphere.

But *seeing* changes on Mars is only the beginning: an observer must transfer that hard-won detailed picture of Mars to paper — in the form of simple pencil sketches — and send those sketches to an organization that can forge them and hundreds of similar observations into a coherent account of Martian behavior in 1988, a vital function performed by ALPO. During the 1988 apparition ALPO will work closely with Marswatch '88, a coalition of professional and amateur astronomers sponsored by the Planetary Society, to educate the public and gather scientific observations of this intriguing planet.

We urge all interested observers to contribute visual observations and color slides to ALPO Mars Recorders, Box 97-0469, Miami, FL 33197-0469. The Mars Section of ALPO also produces a newsletter, the "Martian Chronicle," which active observers can receive by sending eight self-addressed stamped envelopes to the same address.

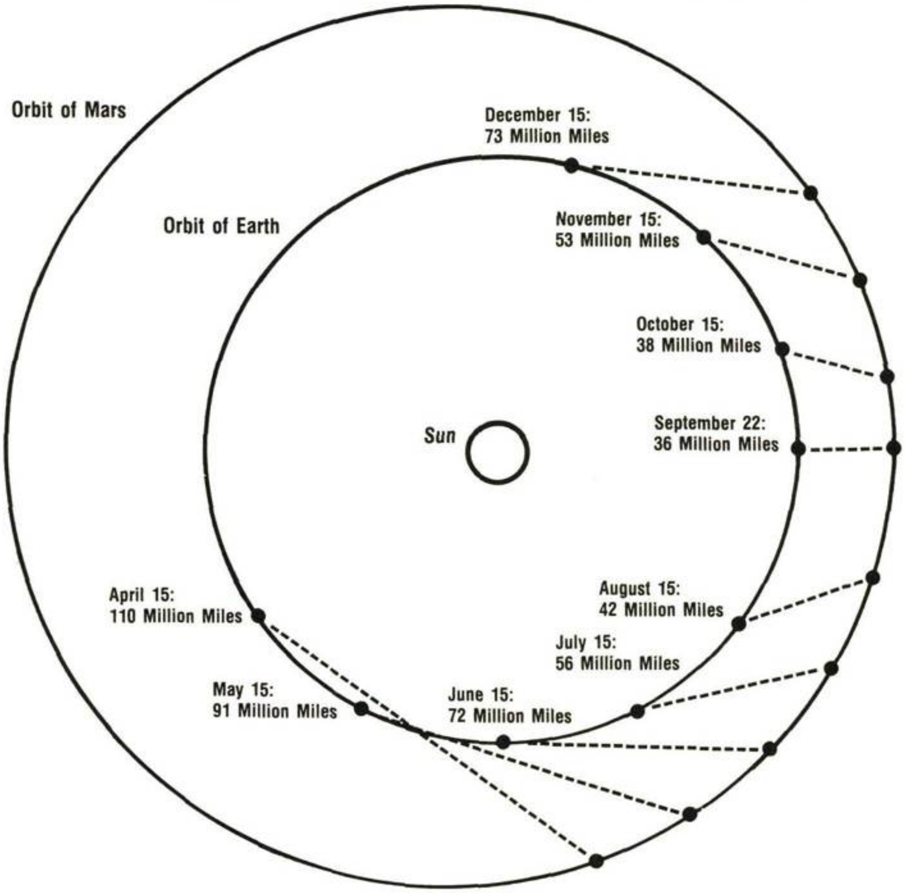
A Great Time to Observe

The 1988 apparition of Mars will be one of the most favorable of the twentieth century for two reasons: Mars will be close to Earth, and it will be close to the celestial equator in our sky.

While the orbit of Earth around the Sun is very nearly circular, the orbit of Mars is not. During opposition, when the Earth and Mars lie in line with the Sun, the distance between the two planets may vary considerably from year to year depending on Mars' position in its orbit. If Mars comes to opposition when it is farthest from the Sun (at aphelion), then it will lie 61 million miles from Earth. But if Mars reaches opposition when it is closest to the Sun (at perihelion), it will lie only 34.6 million miles from Earth. Perihelic oppositions occur every fifteen to seventeen years; the last three were in 1986, 1973, and 1971. In September of this year Mars will reach perihelic opposition again.

Because of the way Mars' orbit is located in space, the very closest oppositions occur when we see Mars against the stars of Sagittarius and Scorpius, the southernmost constellations on the ecliptic. Thus the very best oppositions occur when Mars is too far south for good viewing in the Northern Hemisphere. This is what happened in 1986: the opposition was very close, but Mars was low in the sky in the Northern Hemisphere. In 1988 Mars will reach opposition in the constellation Pisces near the celestial equator. For northern observers, Mars will be 15 to 20 degrees higher in the sky than it was for the 1986 opposition. Because the light

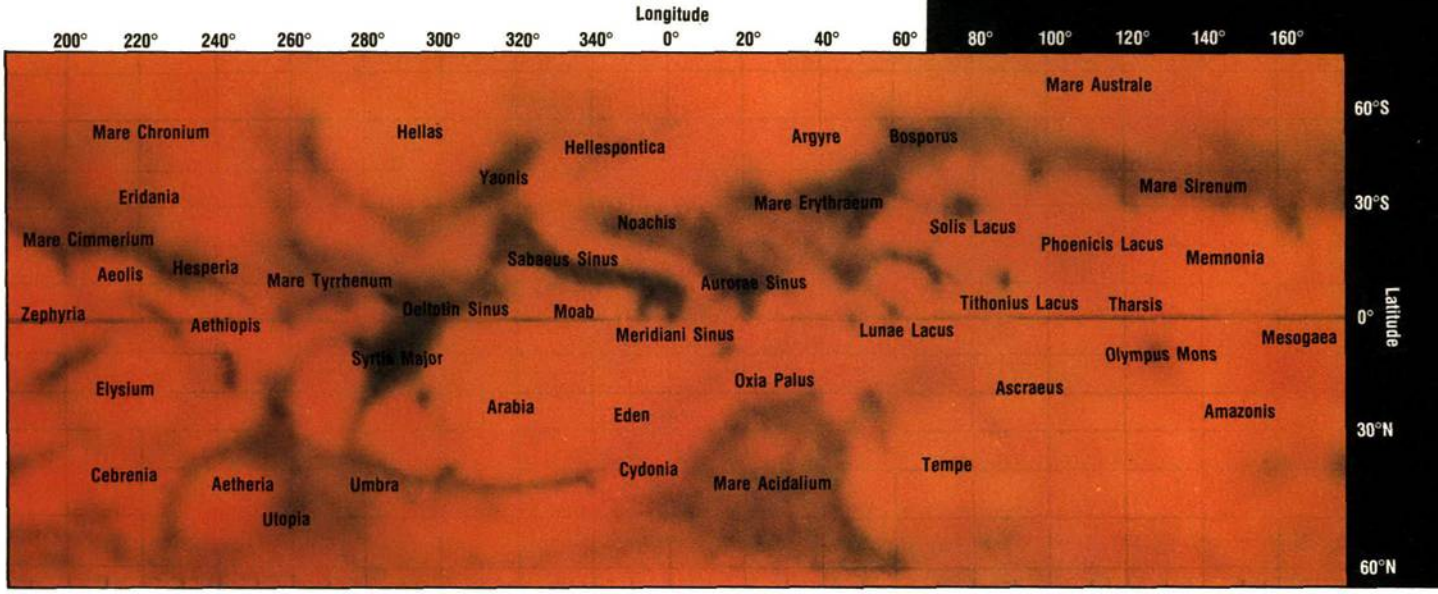
Mars at Opposition: Earth Plays Catch-Up


Orbit of Mars
Orbit of Earth
Sun
December 15:
73 Million Miles
November 15:
53 Million Miles
October 15:
38 Million Miles
September 22:
36 Million Miles
August 15:
42 Million Miles
July 15:
56 Million Miles
June 15:
72 Million Miles
May 15:
91 Million Miles
April 15:
110 Million Miles

During 1988 Earth will catch up to Mars and pass it. The two planets are closest on September 22. The distance between them is shown for each date.

The Features of Mars

The telescopic features of Mars are named for fanciful or mythic oceans and deserts. North appears at the top of this map. Courtesy North American Aviation.


Longitude
200°
220°
240°
260°
280°
300°
320°
340°
0°
20°
40°
60°
80°
100°
120°
140°
160°
Mare Australe
60°S
Mare Chronium
Hellas
Hellespontica
Argyre
Bosporus
Yaonis
Eridania
Mare Sirenum
30°S
Mare Erythraeum
Noachis
Solis Lacus
Mare Cimmerium
Phoenicis Lacus
Memnonia
Sabaeus Sinus
Aeolis
Hesperia
Mare Tyrrhenum
Aurorae Sinus
Zephyria
Deltoton Sinus
Moab
Tithonius Lacus
Tharsis
0°
Latitude
Aethiopis
Meridiani Sinus
Lunae Lacus
Mesogaea
Syrtis Major
Olympus Mons
Elysium
Oxia Palus
Ascraeus
Arabia
Eden
Amazonis
30°N
Cydonia
Tempe
Cebrenia
Aetheria
Umbra
Mare Acidalium
Utopia
60°N

from Mars will reach us via a shorter path through Earth's atmosphere, we will have a better, sharper view of the planet.

At opposition Mars will shine as a brilliant yellow-orange beacon in the sky. Through a telescope Mars will at first present only a shimmering yellow-orange disk. To the visual observer viewing it at 80x magnification, Mars will appear as large as the Full Moon viewed with the naked eye. Mars is then 23.8 arcseconds in diameter. To place this in perspective, this is the angular diameter of a basketball one mile away.

Your first views of Mars will not be exciting. If you begin observing this month or next while the disk of the planet is still small, you may not see any surface detail at all. Don't give up.

As Mars comes closer to Earth during June and July, the disk will grow dramatically and move higher in the sky. During this time, when the disk is small, you must train your "observing eye" to detect the delicate contrasts of the planet, so when Mars nears its maximum size at opposition, you will be ready.

Under excellent seeing conditions a 4-inch telescope should give a sharp image at 200x; an 8-inch may be able to handle magnifications as high as 400x. Generally the best and sharpest views will be at medium-high magnifications of 30x to 40x per inch of aperture or 240x to 320x for an 8-inch telescope. But on nights when the air is still and calm, magnifications of 50x per inch of aperture may prove useful if your telescope has good optics.

In a 4-inch telescope you'll be able to see large surface features, bright clouds, limb brightenings that occur when there's a lot of haze in the Martian atmosphere, large dust storms, the expansion or shrinkage of the polar caps, and "violet clearings" that occur when the Martian atmosphere becomes unusually clear to violet light. Because of the limited resolution of a 4-inch telescope, you'll be able to see these features for only about ten weeks on either side of opposition while Mars is nearby and large.

With a 6- to 10-inch telescope you will be able to follow the same features for twelve to fourteen weeks on either side of opposition, and near opposition you will be able to see smaller clouds and dark features than you could with a 4-inch telescope. You can follow the advance and retreat of the polar caps in fine detail and check for irregularities in the polar cap boundary. You can also watch for changes in the shape and extent of the Martian surface features. Change may occur after major dust storms.

A telescope of 12 inches or more aperture can make any of the features above easier to see and increase the quality of your observations. You will also be able to check for subtle changes in the color of surface features and clouds. One of the most valuable contributions you can make with a larger telescope is a uniform series of high-resolution photographs of the planet in color or in black and white.

1988 Opposition Timetable

On March 11, 1988, just before spring begins on Earth, Mars will appear in the early morning sky as a tiny disk 6 arcseconds in diameter at 22° south declination. Between March 21 and August 24, Mars will move steadily northward at three quarters of a degree per week. From the last week in August through early September it will linger near the celestial equator, well placed for viewing in both hemispheres.

The Red Planet's closest approach to Earth occurs at 03:18 universal time on September 22, 1988. Mars will also reach its maximum disk diameter: 23.83 arcseconds. Between September 19 and 26 Mars will exceed 23.80 arcseconds in diameter.

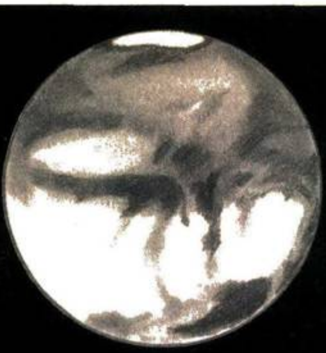
Mars reaches opposition to Earth at 03:25 UT on September 28, 1988, when it is slightly farther from Earth than it was at closest approach. At opposition Mars rises at sunset and is highest in the sky at midnight. For three months on either side of this date — from June 21 to December 9 — Mars will be over 12 arcseconds in apparent diameter and close enough to Earth for careful observation. The chart on page 60 shows the period of good observing clearly.

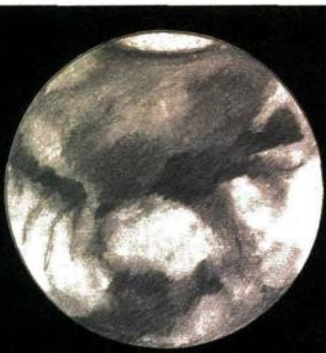
The very smallest Martian features will be visible for over two months in 1988. Beginning on August 19 and extending through October 24, the disk of Mars will exceed 20 arcseconds. During this interval the large volcanoes, like those located within Elysium or in the Tharsis regions, may be visible even in a 6-inch telescope.

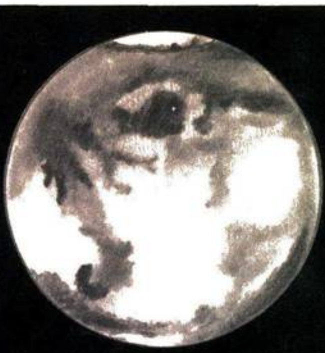
After opposition the Red Planet will move farther north and into the evening sky, but it will be receding from Earth and becoming smaller again. Small surface details and faint atmospheric phenomena can be seen when an apparent disk diameter of Mars exceeds 12 arcseconds. You can see why persistence is a necessary trait of the Mars observer — you'll still be observing Mars in December.

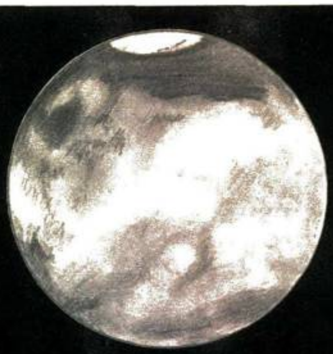
Viewing the Features of Mars

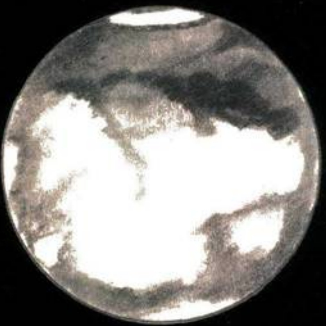
Of all the worlds in the solar system Mars is most Earthlike. It has ever-

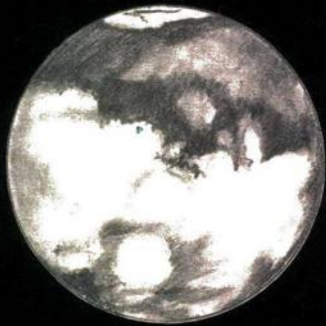

0° Meridiani Sinus

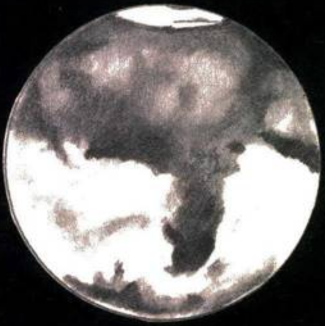

45° Aurorae Sinus

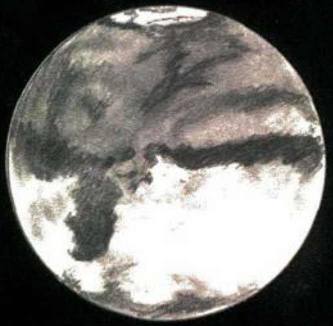

90° Phoenicis Lacus


135° Olympus Mons


180° Amazonis


225° Aeolis


270° Hellas


315° Sabaeus Sinus

changing weather, seasonal thawing of polar ice caps, clouds, vast dust storms, and four seasons. The changes are what you want to observe.

But to recognize *changing* features on the Martian disk, you will have to learn the dark markings and features that stay the same or change only slowly. These features will serve as your reference marks. Use the maps of Mars that accompany this article to learn these features as Mars approaches Earth this spring. During the three or four months closest to opposition you will be able to spot changing features — clouds, dust storms, the recession of the polar cap — with a skilled and practiced eye.

Astronomers have mapped Mars with a latitude and longitude grid just like the one on Earth, except that longitude runs from 0° to 360° continuously for Mars. (Earth longitudes run 180° east and 180 west from Greenwich, England. Mars is easier to understand.) The Central Meridian is the Martian longitude crossing the center of the disk of Mars.

To learn the Martian features, you need only look up the Central Meridian of Mars that's facing Earth on a given day and hour and compare it to maps and drawings of Mars on this page to know which "face" of Mars you're looking at.

Mars rotates once on its axis in 24 hours, 37 minutes, and 23 seconds. The Martian day, called a "sol" by space scientists, is thus a bit longer than a day on Earth. Mars turns only 351° of longitude in twenty-four hours. Consequently, if you observe Mars with your telescope at the same time each night, the Martian surface features will have turned 10° less far onto the visible side of the planet. (Thirty-seven minutes later, of course, Mars will be oriented exactly as it was the night before.)

The net effect is that each Martian feature can be seen best every thirty-six days by an observer at a given longitude on Earth, but someone living on the other side of Earth will see the other side of Mars. Thus, for good coverage of Mars, ALPO would like observers all around the world to sketch and photograph Mars and report these observations.

Observing and Sketching

An observer with a well-made telescope can contribute valuable Mars observations. However, it is important to learn certain standard techniques and use standard reporting methods so your observations can be compared to and used with reports from observers around the world.

Your telescope must have good optics, it must be properly collimated, and the optics must be clean so they can give the best contrast. You should observe from an open grassy area, away from asphalt and concrete that soak up daytime heat and release it at night causing turbulence, or "bad seeing." City lights don't harm planetary observing, so you can observe Mars even from New York or Los Angeles! But you must allow your telescope to reach outside temperature before attempting any critical observing, and you must conscientiously work at educating your "observer's eye" with lots and lots of observing.

You will need good quality eyepieces, but you don't need the expensive wide-angle types. Orthoscopics and Plossls are fine. A set of color filters is tremendously helpful but not absolutely necessary. Color filters increase contrast between areas of differing color, permit you to separate clouds at different levels in a planetary atmosphere, and reduce light scattered from a too-bright planetary image. All told, they increase the sharpness of surface and cloud details you will be trying to observe on the planet Mars.

A yellow filter brightens the ocher-colored Martian deserts and darkens the greenish and brown features. Orange increases contrast between light and dark features, penetrates atmospheric haze, and helps you see yellow dust clouds. Red goes even further, yielding maximum contrast of surface features and helping you see dust clouds.

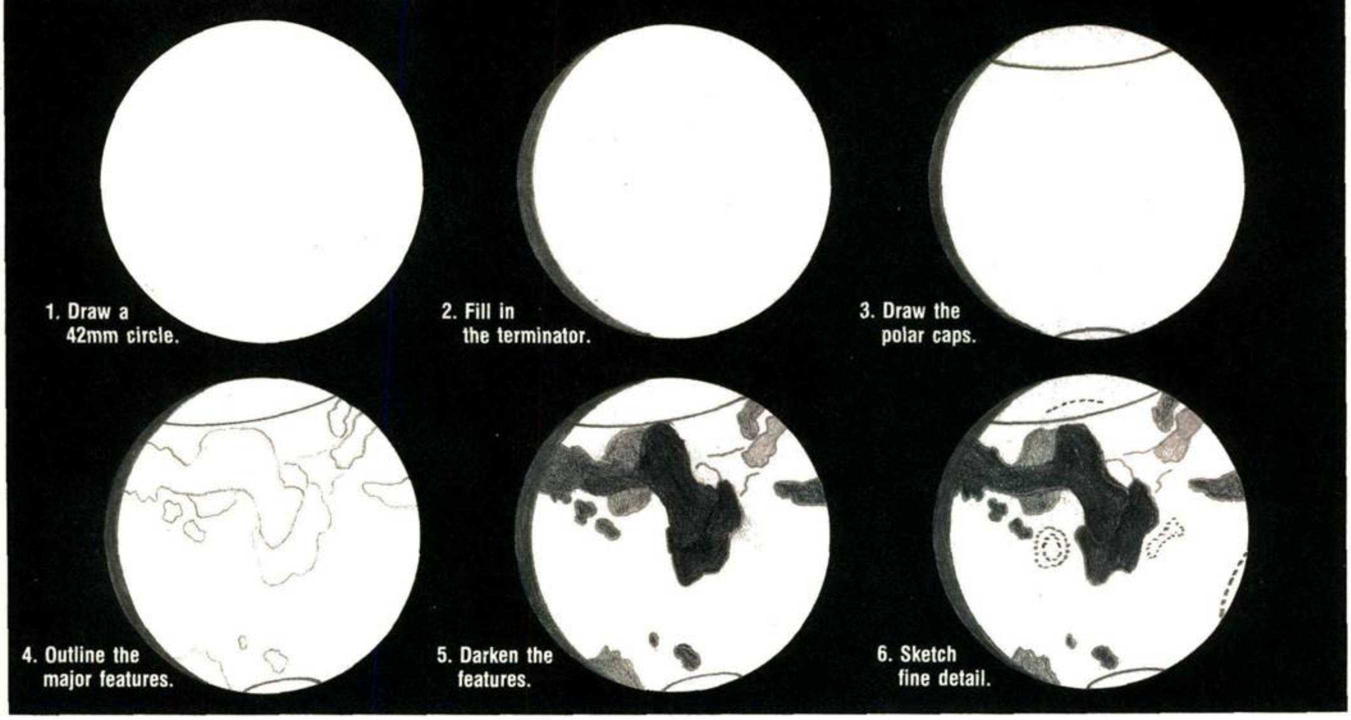
Green, blue, and blue-green filters brighten atmospheric features and darken the surface. Violet filters go even further, bringing out haziness on the limb of the planet, small equatorial clouds, and clouds over the poles.

Used intelligently, filters help you see more than you could any other way. You can buy glass filters from companies that advertise in ASTRONOMY or obtain low-cost gelatin filters from a camera store. Your filter set should include all of the colors mentioned above, plus magenta to enhance polar cap contrast.

Many potential planetary observers say they can't draw, so they never even try to make planetary drawings. But drawing planets is not fine art. Instead it's a careful record of what you saw with your telescope. An ugly drawing is just as useful as a masterpiece — so don't let any lack of artistic ability stand in your way.

Index cards are perfect for planetary sketching. Put one observation on each card, and be sure to include all relevant information on the card. Cards are convenient at the telescope, easy to stuff in the pocket of your shirt or coat, and easy

How to Sketch Mars



1. Draw a 42mm circle.
2. Fill in the terminator.
3. Draw the polar caps.
4. Outline the major features.
5. Darken the features.
6. Sketch fine detail.

to store in date-order in a file box. Both 3x5 and 4x6 cards work well.

To simplify comparing and measuring sketches from many observers, ALPO's "standard" Mars sketch is 42 millimeters in diameter. The original reason for this is that Mars is 4,200 miles in diameter, so the image scale is a convenient 100 miles per millimeter. Today it makes sense to maintain a uniform format even if the mix of units seems a bit odd.

Begin a sketch by drawing a 42-millimeter circle, and then rough in the phase of the planet (Mars will have a pronounced gibbous appearance in August) and the polar cap. South should be at the top of your drawing. Sketch the major features with a few rough outlines, then use a pencil to block in the areas of these features and indicate how dark the features are. This preliminary stage should take no longer than ten to fifteen minutes. If it takes longer, the rotation of Mars will distort your drawing. Complete the sketch by adding fine details and cloud features.

Your goal is not to make a pretty drawing but to record the visible features of the planet. Don't be afraid to indicate clouds with dashed lines or show bright spots with dotted lines and labels. Make notes about everything you can see or even suspect you can see, including color, visibility of clouds and features with and without color filters, type of filter used (i.e., Wratten 47, or Optica b/c medium blue), and the brightness of features.

As you become more familiar with Mars, your value as an observer will increase because you will learn to recognize all the standard features of the planet and thus become able to recognize subtle changes when they occur. Don't expect to learn the names of all the features right away; there are too many of them and the names are pretty strange. If you learn the names of the major features from the map on page 62 and then locate these features on the planet as it's approaching Earth, you'll soon know them and the process will have been quite painless.

Standard ALPO observing report forms are 8-1/2" by 11" sheets of paper with three 42-millimeter Mars circles at the top of the page and lines for all the necessary observing data below. To make a report to Marswatch '88 and ALPO, copy your original observations from your cards onto report forms. Be sure to include all notes and comments. Do not put observations from more than one night on a report form because observations are sorted and compared to other observations on a night-by-night basis.

Martian Polar Regions

The Martian polar ice caps are bright, easy to see, and undergo fascinating seasonal changes. They thaw in the spring in each Martian hemisphere and re-form each autumn in an annual cycle of the seasons.

The southern polar region of Mars will be tilted toward Earth during most of this apparition. On February 12, when Mars is still quite distant, we will view the planet exactly equator-on. On March 21, we'll see Martian latitude 11° south centered on the visible disk, and by June 17, we'll see latitude −24°. At opposition the tilt will have dropped to 21°. Observers will have a superb view of the southern hemisphere and of the south polar cap throughout the apparition.

Around the second week in June we expect the winter haze hood over the polar region to dissipate, beginning at the edges. This will make the cap look like a Life Saver candy with bright white ice at the edges and gray in the middle.

By the last week of June the south polar region should be free of its hood and will appear white all over. Look for bright white projections that detach themselves from the polar cap and a number of dark rifts in the cap. Watch around the second week of July to see if the "Mountains of Mitchel" (at Martian longitude 225° to 230°) remain snow-covered as the cap recedes.

Clouds and Hazes

Mars has an amazingly dynamic atmosphere considering it is less than one hundredth as dense as Earth's atmosphere. White water clouds, bluish limb hazes, and bright surface ice-fogs and frosts are regularly seen and tracked by Mars observers. Over many years astronomers have learned a lot about when and where these atmospheric features will occur; much of the knowledge is based on observations made with small telescopes.

Orographic clouds form when moist air rises over a high spot. On Mars these whitish water clouds form in spring and summer on the upper slopes of the large Martian volcanoes — Olympus Mons, Ascraeus Mons, Pavonis Mons, Arsia Mons, and Elysium Mons — and between Tharsis Tholus and Valles Marineris.

We watched such clouds form during the 1984 opposition in the northern summer after the north polar cap had begun to thaw rapidly and again in 1986 after rapid thawing of the south polar cap began. Look for orographic clouds using blue and violet filters.

Limb haze appears as a bright, misty arc

When You'll See Martian Features

UT Date	Central Meridian	Major Feature
Sep 2	136°	Olympus Mons
5	109°	Phoenicis Lacus
8	82°	Tithonius Lacus
11	55°	Aurorae Sinus
14	28°	Argyre I
17	2°	Meridiani Sinus
20	335°	Sabaeus Sinus
23	309°	Deltoton Sinus
26	282°	Hellas
29	256°	Amenthis
Oct 2	230°	Hesperia
5	203°	Elysium
8	177°	Amazonis
11	150°	Mare Sirenum
14	123°	Arsia Mons
17	96°	Solis Lacus
20	70°	Lunae Lacus
22	52°	Aurorae Sinus

Which face of Mars is visible from the eastern United States one month before and after opposition? The Central Meridian is shown for 0230 hours universal time, or 10:30 p.m. eastern daylight time (EDT) of the civil date prior to the UT date listed. To find the Central Meridian for other dates and times, subtract 9.2° for each day after a tabulated date and then add 14.6° for each hour after the tabulated time. A major surface feature that will be on or very near the Central Meridian at that time is listed.

of light on the sunrise or sunset limb of Mars. It appears at the limb because there the observer looks through a long path in the upper Martian atmosphere, which may contain carbon dioxide crystals, fine dust, cirrus-type water clouds, or a mixture of these. Consequently the presence of limb haze is a very sensitive way to detect unusual weather activity or polar phenomena. When you see haze, note its location, color, and density, as well as the filters used to see it.

Fogs and frosts, often called bright patches, form in the chill of the Martian night, rotate with the planet, bake off in the morning sunlight, and usually disappear by local noon. You can tell them from elevated clouds by examining them with blue, blue-green, and yellow filters. High clouds look brightest with a blue filter, while low-lying fogs look brighter with a blue-green filter than they do in a blue or a yellow filter. Surface frost looks brightest in green and yellow filters and is hard to see with a blue filter.

The behavior and location of bright patches also help distinguish these patches from clouds and limb haze. Fogs normally form in valleys, linear depressions, basins, and on upper slopes. Frosts are usually seen on deserts, plateaus, mountains, and floors of large craters. Pinpointing the location and seasonal occurrence is important to the study of Martian weather patterns.

Mars normally shows only a bright, featureless disk in violet light because the Martian atmosphere scatters short wavelengths. When a violet clearing occurs, the large, dark surface features can be seen through the atmosphere with a Wratten 47 filter. Although the debate over the cause of this phenomenon has raged for decades, no explanation of violet clearing is generally accepted.

Dust Storms

Observations of Mars indicate that yellow dust storms occur around the time of southern summer solstice, soon after Mars reaches perihelion. During the 1971 perihelic apparition a dust storm first observed in the Serpentis-Noachis region spread rapidly and soon completely obscured the surface of the planet. On October 12, 1973, as Mars neared perihelion, a yellow dust cloud appeared next to Solis Lacus, developed rapidly, and enveloped the entire Martian globe with dust. (The *Mariner 9* spacecraft had to wait in orbit three months for the 1971 storm to subside before it could begin observations of the planet.) When a great dust storm reaches maturity, Mars' disk appears bright orange and Mars' surface features are obscured.

We expect the Martian dust storm season to begin about June 1. After this date observers should be alert for yellow dust clouds in the northeast Hellas Basin, the Serpentis-Noachis region, and the Solis Lacus region.

Needed: Photographs of Mars

Photography is a valuable adjunct to visual observing. Photographs constitute a permanent, impersonal record that can be studied later. Even photographs that do not seem particularly sharp may reveal cloud features on careful examination. If you have an 8-inch or larger telescope and an interest in astrophotography, we would like you to photograph Mars for us.

Because Mars presents a very small angular diameter, you will need to enlarge the Martian image so that film defects and film grain are not confused with real surface detail. The size of the Martian image should be no less than one twentieth of an inch (1.5mm) in diameter on fine-grain black-and-white film or one tenth of an inch (3mm) on color film.

The only practical way to achieve a large image diameter is with eyepiece projection. (See "High-Resolution Lunar and Planetary Astrophotography" by Rick Dilsizian, Photography in Astronomy, January 1988.) The following focal lengths are required to produce a one tenth-inch-diameter image at the film with various apparent sizes of Mars:

Angular Diameter (in arcseconds)	Minimum EFL (in inches)
12	1720
18	1150
23	900

We have found that Technical Pan film is excellent for black-and-white Mars photography and that Ektachrome 200 is good for color photography. Under normal conditions the following exposure times work well:

Effective Focal Ratio	TP 2415 (ISO 125)	TP 2415 (ISO 240)	EKT-200 (ISO 200)
f/100	1.4	0.7	0.8
f/150	3.0	1.6	1.9
f/200	5.4	2.8	3.4

(Note: Technical Pan Film is developed to an ISO of 125 in 100:1 Rodinal; to an ISO of 240 in 25:1 Rodinal developer.)

Persistence: Byword for Observers

Above all else we're looking for observers who want to stick with a regular Mars observing program for at least six months during the 1988 apparition of Mars. We'd like to work with you to document the changing features of the Red Planet in 1988 so we can compile a better record of the planet than has ever been compiled before.

We also encourage astrophotographers to shoot and send us well-documented photographs of Mars. Observers who own or have access to large telescopes can best contribute to this work. Color slides or black-and-white prints are both useful; black-and-white photos taken through color filters are especially valuable.

We hope observers who don't have the time to sketch Mars every clear night will observe Mars whenever possible just for the fun of it. Mars is a magnificent planet, and we'd love you to experience it.

Jeff Beish and Donald Parker are the Mars Recorders for the Association of Lunar and Planetary Observers and founders of the Institute for Planetary Research. Beish has been a Mars observer since 1973 and is currently cataloging 12,000 observations of Martian weather phenomena reported by observers. Donald Parker is well known for his outstanding photographs of the planets, many of which have appeared in ASTRONOMY.

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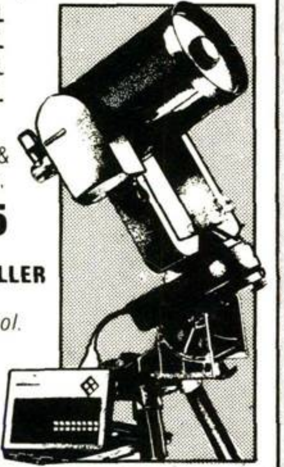

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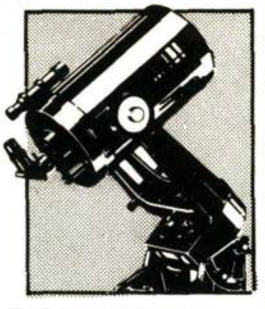

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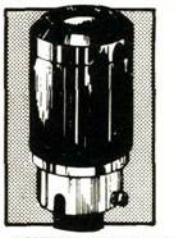

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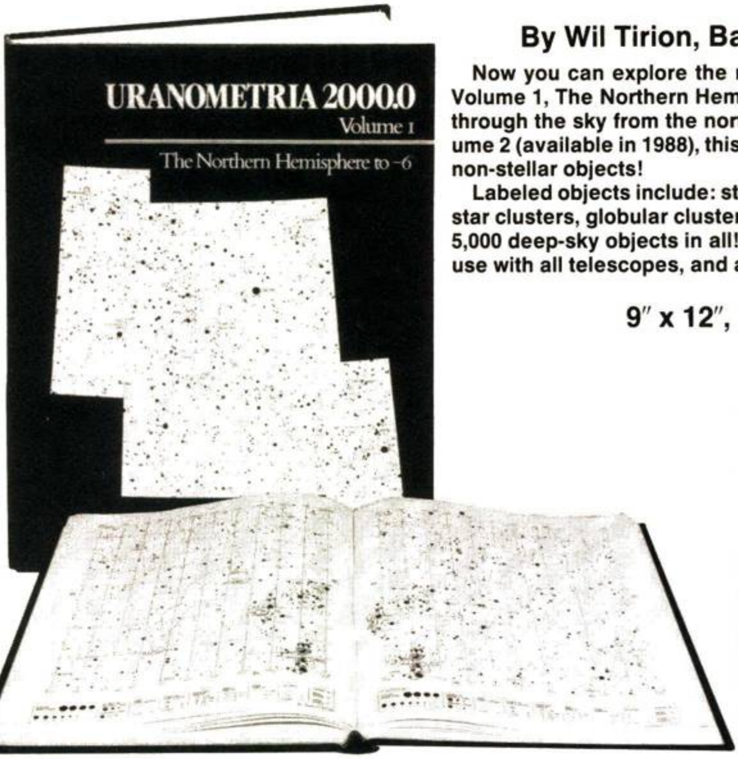

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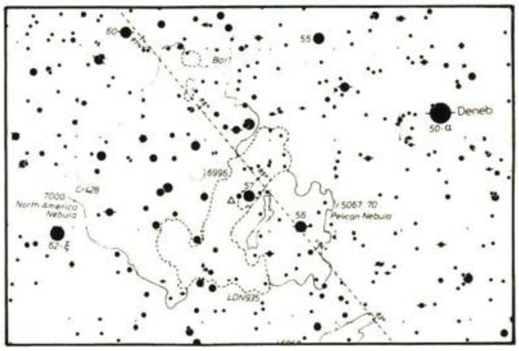

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Photography
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Make Your Own Black-and-White Prints

by Matthew F. Willson

Some astrophotos in this world never get a fair chance. The negatives they're made from are taken to a commercial printmaker who is used to making prints of mom, pop, and the family car. But astrophotos contain delicate subjects that require careful, custom printing so they'll appear as good as they possibly can. Do your astrophotos a favor by making your own black-and-white prints at home. For a relatively small investment you can set up a darkroom in a bathroom or attic and in a short time learn how to make the most out of your precious pictures of the sky.

The first step in setting up is to get the materials you'll need for a darkroom. You'll need an enlarger, which you can find at any photo supply store. You need not buy a sophisticated model, especially if you're a beginner, simply one that allows the basic operations of changing the amount of enlargement and using filters during exposures. A suitable enlarger may cost $200, but it is an investment that will pay off in improved photo quality. You'll also need three developing trays, a stock of developer, stop bath, fixer, and a supply of photo paper. Finally, get a pair of tongs for handling the paper as it moves through the developing process. The total cost to start a darkroom should be about $300.

To make snappy, impressive black-and-white prints, you'll need to choose a photographic paper. For astrophotos, select a glossy paper. Carefully look at the contrast grades on different papers, because the contrast grades determine how the print will turn out. The standard rating ranges from 0 (low contrast) to 5 or 6 (high contrast with few gray tones between black and white). Generally you'll find that faint objects appear best when printed on high-contrast papers, while bright objects work well on low-contrast papers. Does this mean you have to keep six different types of paper in stock? No. Multigrade papers allow you to achieve different contrast prints by using color filters.

Choosing Your Format

Another important consideration is the paper holder. Usually this device has a few slots to hold different sizes of paper and a sliding clamp on top. The slots allow you to hold the paper securely and make a white border around the image on the print. In the darkroom, store your paper in a light-tight box and turn on the enlarger lamp to adjust the paper holder.

Each inch of the short side of your paper corresponds roughly to a 1x enlargement. At about 9x, the area of your print will be about 9" by 13.5" and you would probably use 11" by 14" paper. With most paper sizes you will sacrifice a small part of your negative, which measures 24mm by 36mm. This yields a length to width ratio of 0.67. Most paper sizes have ratios slightly higher than this, so some of the long dimension of the photo won't fit on them.

Keep in mind that fine-grain films can be enlarged much more than grainy films. With a Tech Pan negative you will be able to make a print of the entire frame virtually as large as you want or make an 8" by 10" print of a small, detailed section of the negative.

Preparing Your Negative

Take care to keep your negatives absolutely spotless. An infinitesimal lint strand on your film will show up like six inches of fuzzy twine on an 8" by 10" enlargement. Store your negatives in plastic sleeves, and when you take the film out to print it, gently wipe the film with a camel's hair brush or blow dust with a photographer's can of compressed air. Be sure not to touch the film surfaces with your fingers. Remove the film holder from the enlarger and blow or brush off both surfaces of the glass, even if you can't see any dust.

Place the holder back into the enlarger and carefully set the film into the holder. Be sure to insert the film with the emulsion side down, facing your paper holder. (The dull side is the emulsion side.) Make sure the image you see is exactly how you want your final print to look. If it isn't, move the negative or move the paper holder until you get what you want.

Making Your Exposure

Now focus the image of the negative

Darkroom Supplies for Printmaking

You will need these basic supplies to make black-and-white prints at home. The quality and cost of materials will vary, but you should expect to buy everything needed for a bathroom or basement darkroom for about $300. Once you master the basics, you may want to add equipment when you become involved with more advanced techniques.

An **enlarger** should accept 35mm film and have a sliding, variable magnification head and a slot for color filters.

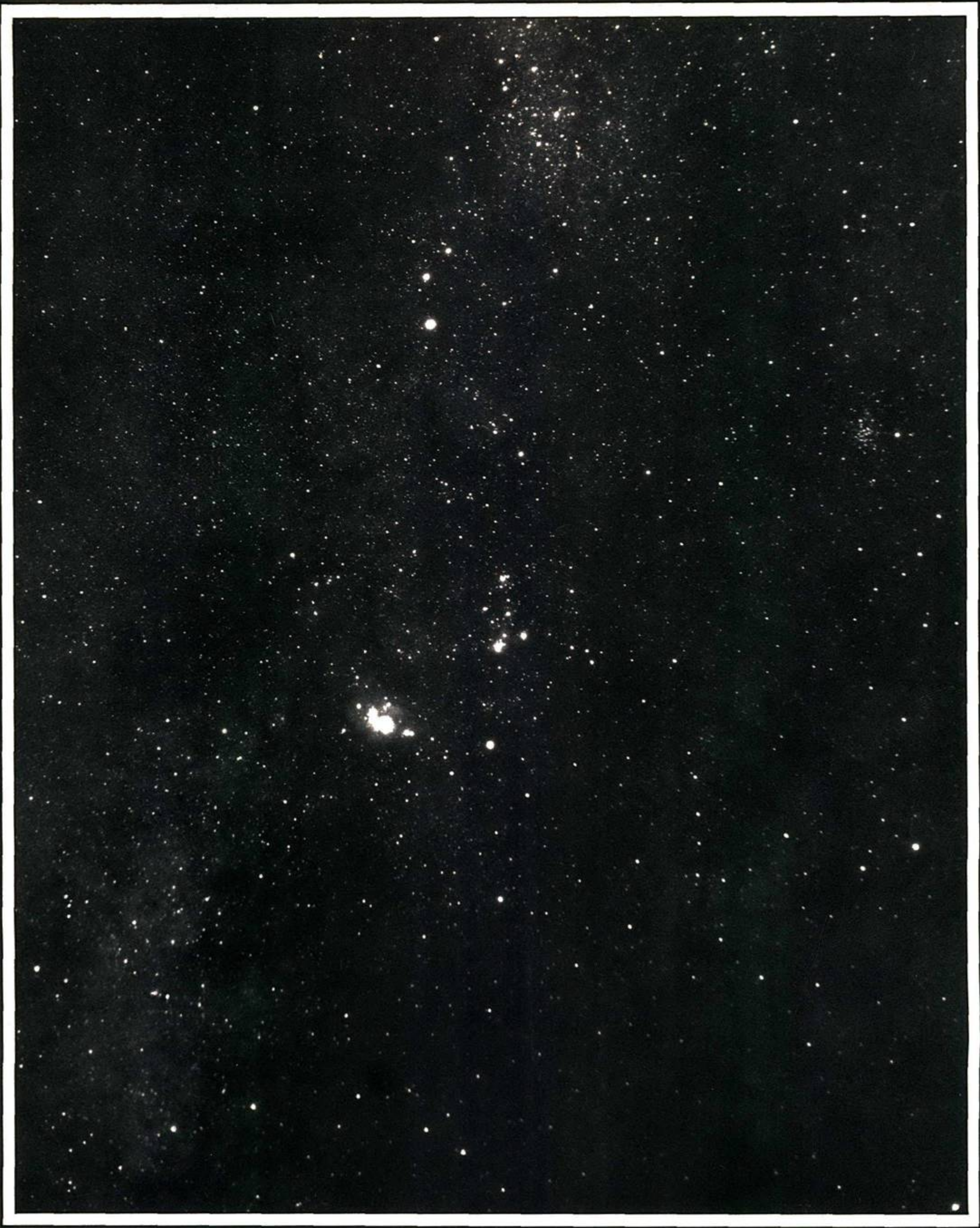
Three **developing trays** hold developer, stop bath, and fixer. These should be one size larger than the paper you use (if you use 8" by 10" paper, use 11" by 14" trays).

The specific types of chemicals — **developer, stop bath, and fixer** — you use depend on the type of paper you use.

Glossy **photographic papers** are best for astronomical subjects, and multigrade papers let you achieve a range of contrast in a single box of paper.

Tongs are used for handling paper in the trays.

A soft **brush** or can of **compressed air** removes dust from negatives and prints.



A wide range of contrast, bright white highlights, and subtle faint detail — such are the attributes of a well-made black-and-white print. Photo by Matthew Willson, who used a 135mm f/4 lens, hypersensitized Tech Pan film, and a 10-minute exposure.

Artful Dodging: How to Keep Subtle Detail

Hours spent in the bone-chilling cold of a crystal clear winter night. Accurate polar aligning, careful guiding, patient control every step of the way. This is astrophotography. And now I'm standing inside the next morning and it's time to remove my precious strips of film from the developing tank. I look into the tank with great excitement: There it is! Negative #4 shows incredible detail! The spiral arms in M31 look sensational. Examining more closely, I see the nucleus barely shows its dark dust lane. The bright part of inner M31 appears overexposed and lost is the subtle detail I was hoping to record.

But all isn't lost. A bit of darkroom magic can make negative #4 as impressive as I had wanted it to be. I need some way of darkening areas that are too light and brightening areas that are too dark. By "dodging" the print in the darkroom, I can preserve details in the faint, outer areas of an image and also keep detail in the bright regions. The technique is fairly simple: Place your hands or a cut-out tool between the enlarger lens and the photographic paper to control the amount of light reaching various parts of the print. Using your hands may seem crude, but it is effective because your hands can be changed into an infinite variety of shapes.

Another alternative is buying a dodging kit at the local photo supply store. Dodging kits contain wire holders, an assortment of cut-out shapes, and sheets with holes punched in them. All have a black matte finish to minimize dispersion of light during exposures. It is easy to prepare your own dodging devices. In fact, some applications may require a tool with a special shape that must be handmade. All you need to make a dodging tool is some thin cardboard; a thin, firm wire; and some black spray paint. In a few minutes you can create an S-shaped card perfect for burning overexposed parts of the Moon without losing detail near the terminator.

There are two steps to dodging. If you want a portion of a print to show less exposure than the negative, than you'll "hold back" detail. If you want to give extra exposure to an area to bring out fine detail, you'll "burn in" that part of the negative.

The art of dodging — the challenge of doing it well — is creating a print with areas of different exposure that merge indistinguishably into one another. You must constantly move your hands or the dodging tool while dodging or burning, or you will see the effects of the process on the finished print. The hand motion must be random. If you move hands in a repeating pattern, you'll give varying amounts of exposure to the dodged area and see it on the finished print. Naturally, the larger the difference in exposure times between two adjacent areas, the more critical this factor becomes.

If you hold the tool close to the paper, the shadow cast will be very sharp and cause a pronounced border between areas of different exposure. If you hold the dodging device close to the enlarging lens, the light will be scattered far over the picture, which softens the border between the two exposure areas but results in the scattering of additional light into areas that possibly do not require it. You should hold your hand or the device almost equidistant between the lens and the paper. The exact distance selected is a means, in addition to the constant motion, of controlling the transition of tones between the dodged and nondodged portions of the print.

Making a dodged print involves a lot of trial and error. There are no exposure tables or rules that will enable you to calculate the precise dodging technique required. The variables you will deal with are length of exposure, how much hold-back and burn-in is required and where, what kind of dodging devices should be used, where to position the device relative to the paper, and what kind of motion gives the best transition. When trying to formulate a plan of action, you should remember that areas that appear too light on a print require burning in, while areas that are too dark and lack detail must be held back.

The first step is to make a test print. From the different exposure strips on the test print you should be able to pick the optimum exposure values for the different parts of the print. The exposure time for the major portion of the print is called the primary exposure. The f/stop of the enlarger lens should be set so that the primary exposure will run about 20 seconds. This allows sufficient time to hold back any portion of the print and use the necessary constant motion of hand or tool without prolonging the amount of time you are dodging. Next, make an additional exposure if you need to burn in any areas of the print.

Keep a written record of dodging times so any required modifications can be care-

using the widest f/stop of the enlarger. Try to get the sharpest image you can on the paper holder, and don't worry about the difference in thickness when you insert paper. This won't cause any noticeable shift in focus. If you find that focusing the image by eye isn't satisfactory or you want higher precision, look for a grain focuser at a photo supply store. This device uses a flat mirror and an ocular so you can inspect the focus critically. A grain focuser is a valuable addition to any darkroom.

Once the enlarger is focused, the exposure time you'll want to use depends on a number of factors, including subject, size of enlargement, type of paper, and film density. This may sound complex, but you can narrow the possibilities. First, the larger your final print will be, the longer you will need to expose. Based on a satisfactory print of one size, you can calculate the exposure times for a different size print by the equation $e = x(n/L)^2$, where e is the new exposure time, x is the old exposure time, L is the old print enlargement, and n is the new. For example, if you made a good exposure of 8 seconds on 5" by 7" paper, your exposure on 8" by 10" paper should be 5 seconds multiplied by $(8/5)^2 = 12.8$ seconds.

The second factor in exposing paper is the type of paper you use. Exposure times can vary a great deal between papers. Even the multigrade paper I use has exposure variations between contrast levels 3, 4, and 5. Fortunately paper comes packaged with data that explains a good deal about the paper's relative speed. Read this information before making prints.

The third variable in exposure times is film density. Occasionally, hypersensitizing will fog a film relatively darkly, although contrast (the important stuff) generally isn't affected. In most cases you'll know by sight if your negatives are abnormal.

If you want to get a general idea of how a number of negatives will look when printed, make a contact print. Do this by laying your negative strips on a piece of photographic paper, emulsion to emulsion. Then run your exposure for the same amount of time you would if you were enlarging a single negative to the size of your paper.

For your first exposure, make a test print. Stop down your enlarger to f/5.6 or f/8. This helps to keep your image as sharp as possible. Make sure the enlarger light is off, and take out a sheet of paper. The shiny, "sticky" side is the emulsion side. Make sure it faces up. Align your paper in the paper holder, and cover up all but a one- or two-inch strip with a piece of cardboard or posterboard. Make a 5-second exposure. Move the cardboard back an inch or two, and make another 5-second exposure. Continue this process until you run off the end of the paper. Now, you should have exposures running from 5 seconds (the last strip you exposed) to 20 or 30 seconds (the first strip). Once you develop this print, you can estimate the correct exposure, or if you need to, make another test sheet using longer or shorter intervals. Note that many papers begin to lose sensitivity after roughly 2 minutes exposure.

Developing the Prints

After you expose the paper, you have

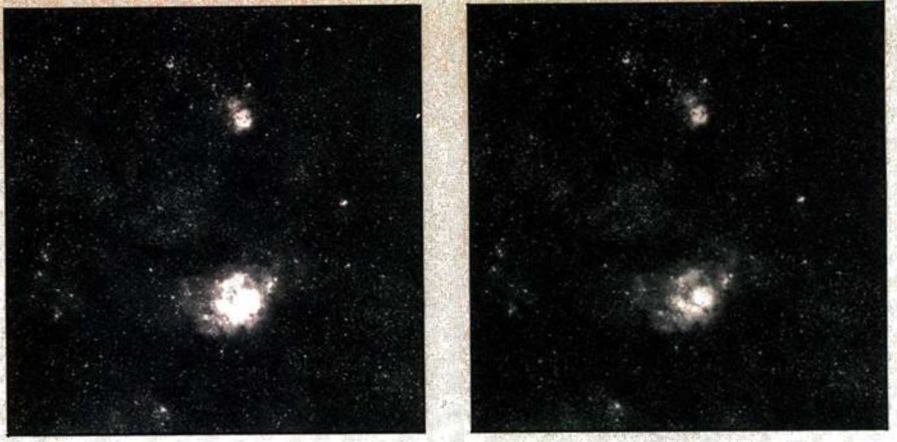
fully planned out for future exposures. Any system will do, but don't trust memory! For example, a plan might read like this:

Expose for 23 seconds at f/8.
Hold back right third for 5 seconds.
Burn upper left corner for 15 seconds.
Use oval #3 for burn; hold near paper.

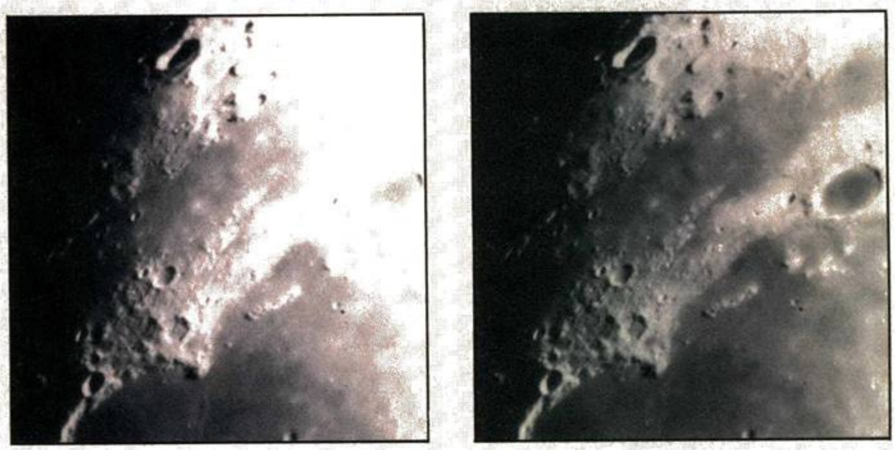
If your first print looks good, you're very lucky. Instead you'll probably need to adjust and rethink a bit to hone in on the perfect dodging system. The best way is to first optimize the exposure values and then concentrate on your dodging technique by varying tools, position relative to the paper, and motion. Each time, rewrite your plan before you start to make the print. As you gain experience, you will be able to arrive at a good print in two or three tries. When you are finished, file a copy of your final print plan with your negative so you will know exactly what to do six months later when you need another print.

Dodging is no substitute for a well-exposed negative. But it can help provide impressive prints from average exposures. My first attempt at dodging negative #4 was not so great. The oval I cut to burn in the nucleus of the galaxy was too big and the spiral arms didn't look quite right. I prepared another tool and two prints later I got a print that looked just right. Dodging isn't too complicated: after improving my prints over a few days of practice, I felt like an old darkroom master.

— *Michael T. Kitt*



A straight print of the Lagoon and Trifid nebulae (left) and a dodged version (right). The photo is a 10-minute exposure on hypered Tech Pan film made with a 5.5-inch f/1.65 Schmidt camera. Photos by Allan Green.



The result of dodging on lunar prints: The straight print of Sinus Iridum and Plato (left) fails to reveal the detail visible in the dodged version. Photos by Michael T. Kitt, who used an 8-inch SCT at f/60, Tech Pan film, and a 1-second exposure.

to convert the chemical, or latent, image into a visual image by soaking the paper in several different chemical solutions.

Developing procedures vary with papers and chemical solutions, and instructions are included with both. Generally, you first slip the exposed paper into a tray of developing solution. Try to get all the parts of the print into the developer at approximately the same time, so the whole print develops at the same rate. The solution needs to be agitated gently by quickly lifting a corner of the tray an inch or two and letting it back down. Be sure all parts of the paper stay under the surface, or your print won't develop uniformly.

After a run through the developer, your print needs to go into the stop bath. This solution, as its name suggests, stops the developing action of the developer.

The third step in developing your print is soaking it in "fixer," which makes the image on the paper permanent. Here, simply make sure the paper stays submerged. Continuous agitation isn't necessary.

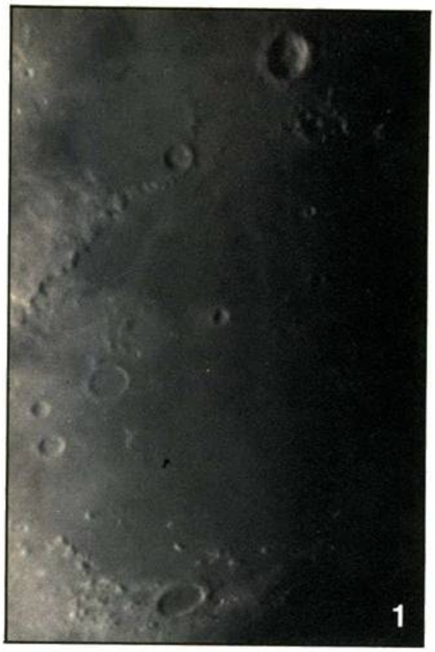
Finally you should rinse the finished print in running water for five minutes and hang it up to dry. Try to keep dust and lint away by slowly hanging the print out of the way. Keeping your darkroom clean helps too. Attach the print to its hanger at two corners, and attach a clothes pin at each bottom corner to keep the paper from curling. If you use an automatic print drier, make your prints don't touch one another as they roll through, or they may stick together.

Although developing a print may sound as if it takes a long time, it really doesn't. For example, my developing sequence runs like this: 90 seconds in the developer, a 30-second stop bath, and a 90-second fixer rinse. Then I simply put each finished print face down in a tray with water trickling in (and then out into the sink). I only have to attend the paper for parts of the first three steps, which amounts to no more than 3-1/2 minutes per print. The automatic drier I use takes about 30 seconds per print, but I can feed in two at a time, so the drying time is not significant. If you hang your prints, the amount of time for each is basically the same.

Those are the basic techniques for printing your own black-and-white negatives. It's simple to get a running start, but it may also be wise to learn more about printmaking from books in a library or at your photo store. After you get your feet wet, these books will allow you to hone your techniques for maximum effect. Now we'll sample some advanced techniques to help you get the most out of your precious negatives.

Burning and Dodging for Detail

When you have a negative that contains detail over a wide range of densities, the techniques of burning and dodging can help maintain detail in all parts of the photo. Understanding that the paper becomes "darker" as it is exposed to more light, you can make an object darker (burn it in), by increasing the exposure time and shading all of your print except the part you want darker. Conversely, you can make an object brighter (dodge it) by shading it while the rest of the paper receives light.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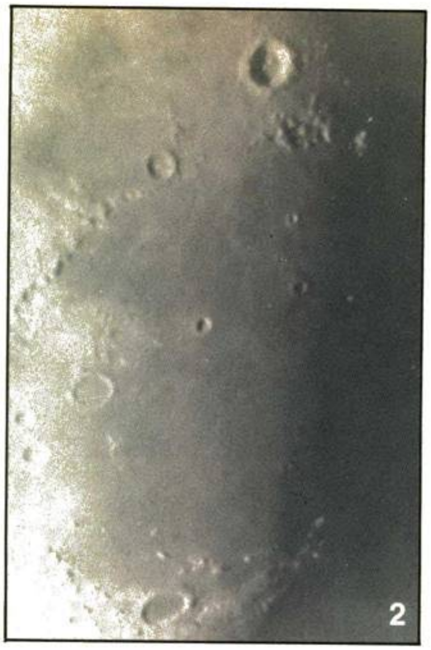
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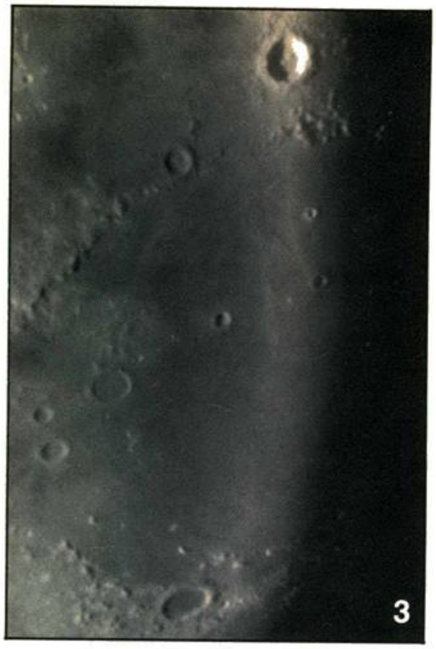
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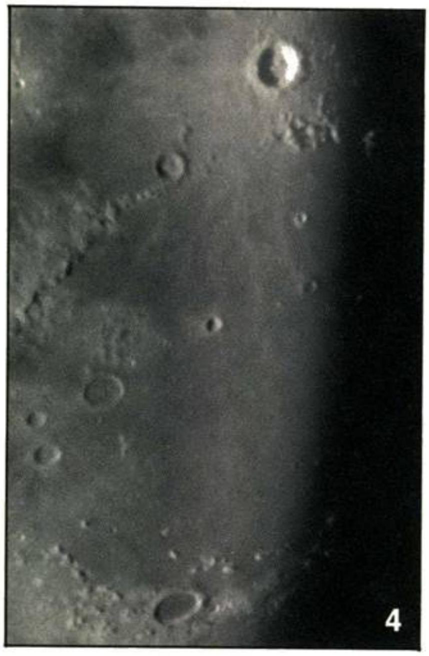
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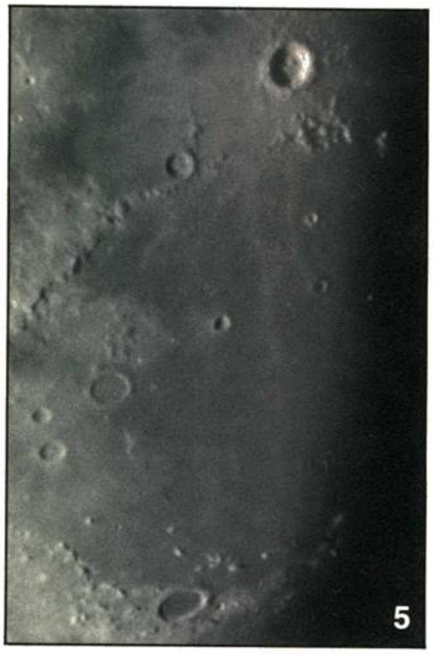
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This sequence showing the lunar surface demonstrates the value of dodging. A straight print (1) yields a disappointing image without detail in the terminator. A short exposure print (2) reveals the detail dodging can bring out. Prints (3) and (4) are intermediate attempts to dodge the image that don't quite capture all of the available detail. Print (5) is a well-dodged example that shows a wide range of detail across the entire photograph. These photographs were made with an 8-inch Newtonian at f/42 and show Mare Imbrium and the craters Copernicus (top) and Plato (bottom). Photos by Ed J. Sommer, Jr.

You can make your burning and dodging shadows with your hands or pieces of paper held in tweezers. Be sure you don't touch the paper or bump the enlarger and keep your shadows moving, or you will make a distinct outline of your shadowing tool on the print.

There is no limit to how long you can burn something in. (The disk of the Moon, for example, may require five or six times as much exposure as the limb.) Be careful, however, because dodging an object too much can leave you with a shapeless, white blob where the object used to be.

Integration Printing: Two Make One

If you have two low-contrast negatives of a single object made with the same optical system, you might experiment with making a single print using both negatives sandwiched together in the enlarger.

The images probably won't match up perfectly, so you may need to cut one of the frames out of its filmstrip and line it up properly with the other negative. Be sure every star image is precisely aligned, or your final print will end up looking like a double exposure. Both negatives should be inserted with the emulsion side down or toward your paper.

After the negatives are properly aligned, you can make the exposure. Because the exposure during integration printing can be up to twice as long as the same shot with one negative, you may be tempted to open the enlarger lens by a stop, but don't. Widening the aperture will only make the star images softer and amplify the tiny difference in focusing between the two film layers. Instead, simply increase the exposure time. You may find this technique helps make the film grain less apparent.

Increasing the Contrast

There are two easy ways to make a low-contrast negative into an impressive final print. The first is simple: Copy the negative onto Tech Pan film with a slide copier to get a positive. If you want slides, you're done. If you want prints, copy the positive onto Tech Pan and make a print from the resulting negative. For the final print a contrast grade of 2 or 3 will be nearly perfect, because the new negative will have more contrast than the original.

If you don't have a slide copier, you can use another method. Make a print from your negative, preferably 8" by 10" or larger, on a contrast grade of 4 or 5. Next, load your camera with Tech Pan and photograph the print. Make several exposures of varying times because light meters don't always provide ideal exposure times for astronomical images. Last, use the Tech

Pan negative to make your final print. Make the exposure at a contrast of 4 and don't print it larger than the size of the print you photographed. The grain of the photographic paper was never meant to be enlarged, and it's easy to see why if you attempt to do so.

Printing from Color Negatives

A special application you might consider is printing color negatives onto black-and-white paper. It's a convenient way of turning a color image into a black-and-white image and can measurably improve weak color negatives. If you are using single-grade paper, you can print directly from the negative. However, if you want high contrast, use a color filter. Remember that a red nebula will show up green on your negative, so you should use a green filter. Most papers are only slightly or not at all sensitive to red light, so it is difficult to print blue objects (red on the negative) like reflection nebulae and the spiral arms of galaxies.

If you use multigrade paper, the process grows a bit more complicated, because the contrast grade of the paper depends on the color of the light that strikes it. The best way to handle the situation is to copy the original negative onto Tech Pan using the appropriate color filter. Then copy the positive you get back onto Tech Pan and make a print from that final negative. You could also copy the original negative onto a color negative film such as VR 100 to obtain a positive. Then duplicate the positive through a color filter onto Tech Pan and you'll get a final negative. With any of these techniques, you lose color and perhaps some resolution but gain a tremendous increase in contrast.

Printing your own negatives offers a lot to a photographer of the sky. You will get better results than a commercial lab can provide and, perhaps even more importantly, you'll learn a great deal about your astrophotographic techniques. Looking back on the printmaking I've done over the last several years, I think the best part of it had to be the countless hours I spent in the darkroom seeing my own images of the universe come to life.

Collecting light onto a piece of film is only half the work of astrophotography. Equally important is printmaking, which you can do at home better than others can do it for you. Photo by Tom Eby.

Matthew F. Willson is an active astrophotographer who lives in Littleton, Colorado. His last article was "Tips for Shooting Clusters and Nebulae," which appeared in the August 1987 issue.

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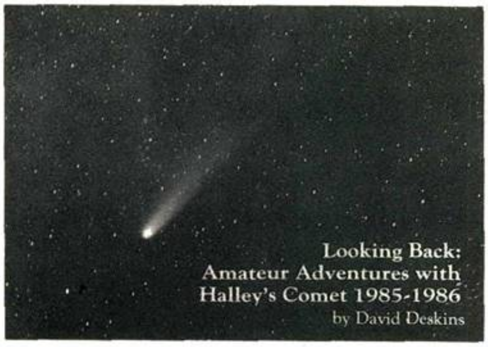

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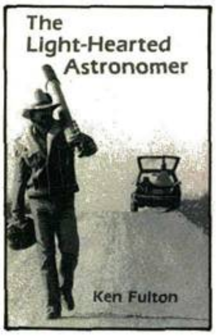

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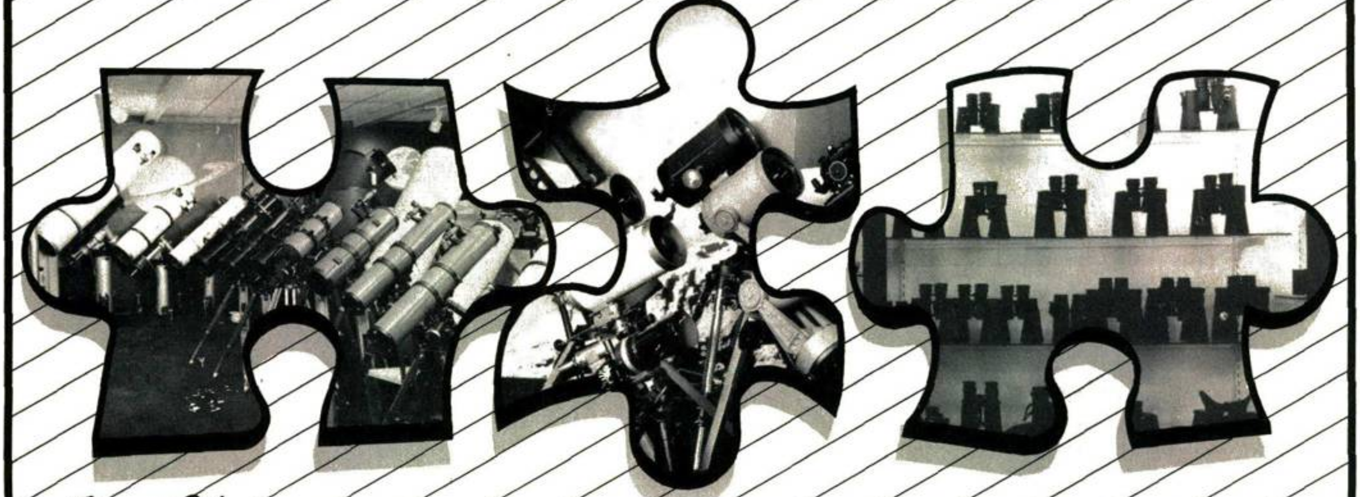

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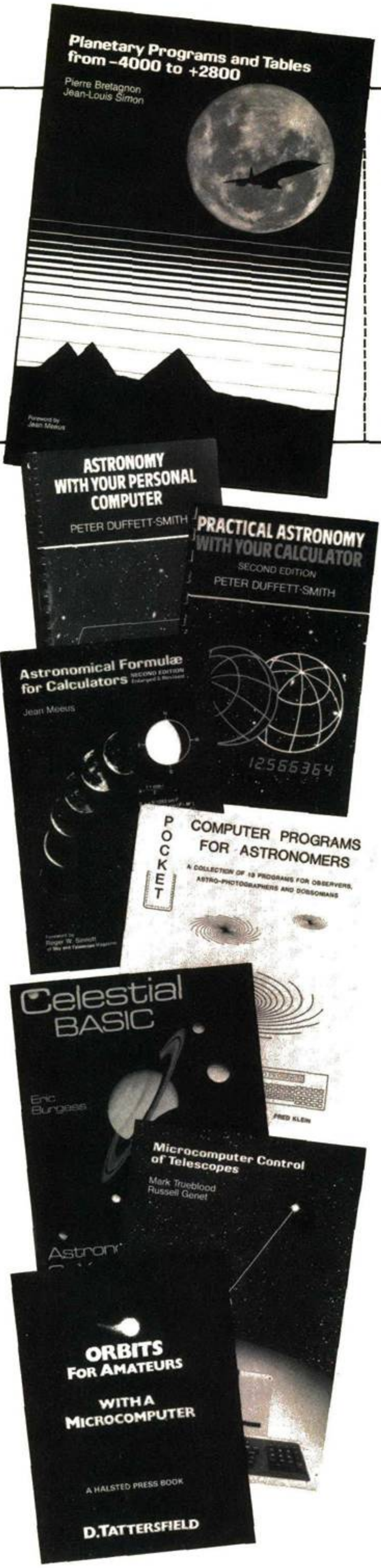
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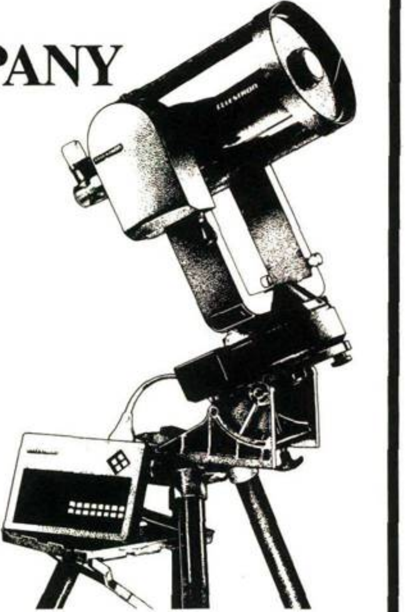

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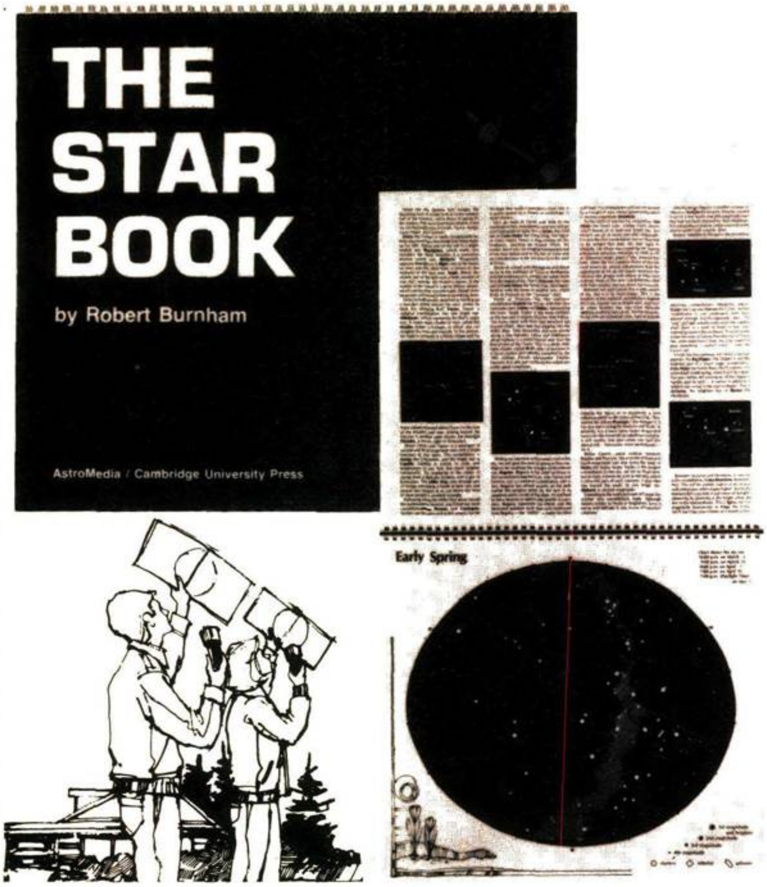

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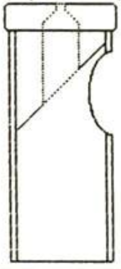

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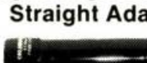

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ASTRONOMY

AstroNews

Galileo Mission to Jupiter Is Still On

Before all is said and done, the *Galileo* mission to Jupiter may go down in history as the most long-awaited, delayed, and redesigned mission in the space program. If successful, however, it will undoubtedly be one of the most scientifically rewarding missions ever undertaken (See "Return to Jupiter" by Gary L. Bennett, January 1987).

In December NASA formally announced that *Galileo* is now targeted for launch aboard the shuttle *Discovery* in October 1989. The announcement marks a new chapter in the mission's arduous history. The initial plans were drawn up in the mid-1970s prior to the *Voyager* launches. The joint mission by the United States and West Germany has been postponed five times, plagued with budget cuts, and threatened with cancellation.

But throughout all the close calls, the mission's goal has endured: to establish an orbiting observing platform to study Jupiter's atmosphere, satellites, and intense magnetosphere. The spacecraft will utilize an array of instruments, including cameras over one hundred times more sensitive than the *Voyager 1* and *Voyager 2* cameras. *Galileo*'s cameras will show features as small as a few meters.

Five months before the encounter a 700-pound probe will be dispatched from the spacecraft to make direct measurements of Jupiter's atmosphere. The probe and the spacecraft will arrive at Jupiter at the same time. As the probe descends into Jupiter's atmosphere by parachute, it will radio back data on such conditions as atmospheric composition, pressure, and density to the orbiter as long as the probe survives (perhaps seventy-five minutes). The orbiter will then relay the data back to Earth. For the following two years the orbiter will continue to study the planet's atmosphere and take detailed photographs of the four Galilean moons.

But though the purpose of *Galileo* is still intact, practically everything else about the mission has changed.

NASA has elected to use a smaller inertial upper stage (IUS) booster built by the Air Force and three gravity-assist maneuvers — one by Venus and two by Earth. The new route to Jupiter will take six years to complete; the direct route using the Centaur would have taken twenty-eight months.

The longer flight path does have advantages though. During the Venus fly by in February 1990 *Galileo* will look for lightning in that planet's atmosphere. In October 1991 the spacecraft will photograph the 10-mile-diameter asteroid Gaspra from a distance of 620 miles. After the second Earth assist, *Galileo* will photograph a second asteroid, Ida (about 20 miles in diameter), in late 1992. Both asteroids are located in the asteroid belt between Mars and Jupiter. These will be the first direct, close-up observations ever made of asteroids. The spacecraft will also accomplish another first: mapping the far side of Earth's Moon in the near infrared.

Spacecraft modifications include the installation of gold solar screens to shield sensitive instruments from the intense radiation of the Sun, an aft-facing low-gain antenna to facilitate communications between the spacecraft and Earth when the spacecraft is facing the Sun inside Earth's orbit, and a sensor to keep the spacecraft oriented toward the Sun so the instruments are protected by sunshields during the trip to and from Venus. In addition, modifications will be made to help conserve the energy of the spacecraft's power supplies, the radioisotope thermoelectric generators (RTGs). Power levels of the RTGs, designed to provide 570 watts of power, will be down to about 500 watts by the time the spacecraft arrives at Jupiter in 1995.

Rocky Pluto Has Methane Crust, Charon Is Frosty

Pluto is not made of ice as astronomers had thought just a few years ago. Rather, Pluto's density implies that it contains a significant amount of carbonaceous matter or silicate rock either mixed throughout the interior or in a differentiated core. Pluto's density suggests that the planet probably formed in the outer solar system, according to planetary astronomers at the October 1987 meeting of the Division of Planetary Sciences of the American Astronomical Society in Pasadena, California.

The new information on the structure and composition of Pluto and its satellite Charon results from mutual eclipses and occultations of the two bodies. (See "Pluto: Enigma on the Edge of the Solar System" by Ken Croswell, July 1986.) Because Charon's orbital plane is nearly edge-on to the Earth, Charon passes in front of Pluto and through Pluto's shadow once each time Charon orbits Pluto. The eclipses began in 1985 and will continue through 1991.

From observations of the light curves, astronomers David Tholen and Marc Buie of the University of Hawaii and others have determined the diameters of both Pluto and Charon, which, combined with the total mass of the system determined from measurements of their orbital period and separation, yield the densities of Pluto and Charon.

"We now have a diameter of 1,145 kilometers for Pluto and 642 kilometers for Charon," announced Dale Cruickshank of the University of Hawaii, "which gives a combined density between 1.8 and 2.0." The individual densities of Pluto and Charon cannot be determined until the ratio of the masses has been determined.

"Their densities mean that Pluto and Charon have a substantial rocky component," said Cruickshank. The rocky component implies that Pluto and Charon formed in the outer solar system and not as cometary bodies much farther from the Sun. Pure ice or ice-clathrate worlds are expected to have densities between 0.9 and 1.2. The ice component also rules out speculations that Pluto is similar to the terrestrial planets, which have densities higher than 3.0.

Pluto and Charon are most comparable in density to the satellites of Uranus and to Jupiter's satellites Ganymede and Callisto. These satellites almost certainly formed in the outer solar system; the similarity in densities implies that Pluto also formed in the outer solar system.

The mutual eclipse and occultation events also allowed astronomers to measure Pluto's and Charon's relative reflectivities. Of the two, Pluto is the lighter, reflecting some 60 percent of the sunlight that strikes it. Charon is relatively dark, reflecting only 40 percent. Because it is darker and therefore absorbs more solar heat, Charon's surface must be warmer than Pluto's.

Astronomers have also obtained individual spectra of Pluto and Charon, which revealed that Pluto and Charon are quite different, from the mutual eclipse and occultation events. Marc Buie and his colleagues, Robert Marcialis and Uwe Fink, independently obtained spectra of the combined light from Pluto and Charon and the spectrum of Pluto when Charon was in total eclipse. By subtracting the data points in the two spectra, they obtained the spectrum of Charon.

"Charon has a spectrum very different from Pluto's," said Cruickshank. Pluto's spectrum shows strong absorption bands of methane, which indicates a gaseous methane in the atmosphere and solid methane surface. In addition, Pluto is distinctly reddish, which indicates that long-chain hydrocarbon molecules are present.

In contrast, Charon's spectrum is "flat" in visible light and featureless. In infrared light, though, Charon shows a strong absorption band at 2.0 micrometers wavelength; this suggests that Charon's surface is frost-covered. Charon's spectrum closely matches that of Miranda, a small satellite of Uranus. Pluto's spectrum shows no sign of water frost.

If Pluto and Charon formed together, then one or both bodies have changed since their formation. Charon's low surface gravity and higher temperature would allow methane to escape from Charon, where it would not escape from Pluto. "Methane is very depleted on Charon," said Sawyer.

Intensive efforts to observe Pluto will continue for at least two more years while the mutual eclipse and occultation sequence continues to provide unique observing opportunities.

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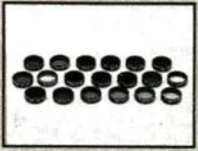

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The zoning proposal, passed on behalf of the observatory by the National Capital Planning Commission in November, would prohibit new construction of buildings within 750 feet from the observatory and would limit heights of new buildings to 40 feet, 10 feet less than the current height limit. The Naval Observatory wants the new zoning restrictions so its ongoing, ninety-year-old astrometric observations are protected from the errors that heat from nearby buildings and light from tall buildings could cause in the observations.

Heat in particular introduces a systematic error in the observations, according to James Hughes, director of the astrometry department and senior astronomer at the Naval Observatory. "It is an error that cannot be worked out simply by making more observations. All observations will be affected," he said.

Observatories around the world rely on the Naval Observatory's astrometric observations — precise measurements of the positions of stars and planets. The Naval Observatory's Transit Circle telescope is the only instrument in the Western Hemisphere performing this type of observing program.

Based on these astrometric observations, astronomers can predict the future courses of celestial objects, and the accuracy of the predictions depends on the accuracy of the observations. These predictions are published in the *Astronomical Almanac* and the nautical and air almanacs, used for navigation by seamen and airmen around the world.

"To move the instruments or impede the observations would mean we would have to start over, building another database on what would essentially be another telescope at another site," said Captain Richard Anawalt, superintendent of the observatory. "What we know about our observations today is only as good as what we know about the instrument historically."

Palomar Observatory Fights the Heat

At this time of year most homeowners are looking for ways to keep the heat inside and the winter cold outside. But at Palomar Observatory astronomers are looking for ways to banish troublesome heat sources inside and outside the observatory that can degrade the quality of the seeing.

Poor seeing is generally caused by either wind or turbulence. Wind disrupts the atmosphere horizontally, while turbulence causes unwanted vertical movement. The smaller, locally generated hot air columns called microturbulence can be controlled, according to Palomar assistant director Robert Brucato and superintendent Bob Thicksten. "There's no one large thing causing microturbulence," said Thicksten. "It's a lot of little

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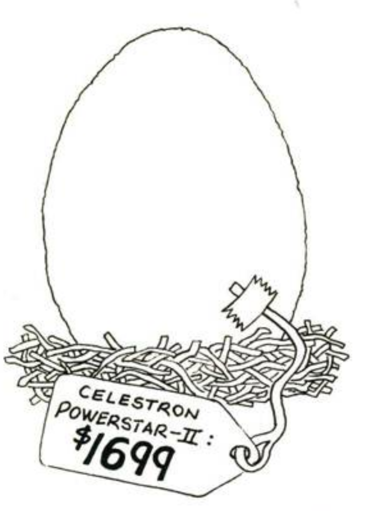
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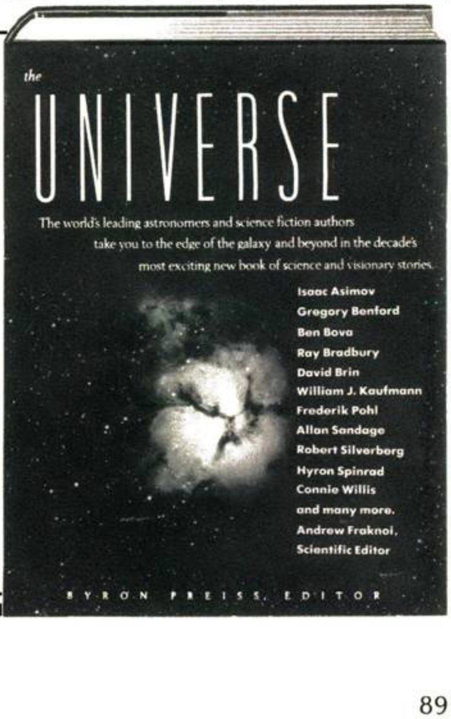
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things you have to watch for."

The most noticeable change is the white paint. All the domes are now completely white. Even the parking lots near the domes have been painted white. The white paint greatly reduces the heat absorbed by the asphalt and thus the amount of heat rising from the lots during cool night hours. Less rising heat translates into reduced microturbulence.

Microturbulence is generated inside the domes too. An infrared survey of the dome interior was performed with a video camera to locate heat sources. As a result, highly reflective Mylar tape has been affixed to the outside diameter of the upper part of the prime focus cage. The observing floor is being insulated from the office and workshop areas on the ground floor below, and the maintenance crew is currently fabricating a false ceiling carrying R-30 insulation for the ground floor. Two feet of ceiling insulation has already been added to the data room, which sits close to the telescope on the observing floor.

While Brucato stressed it is still too soon to declare an exact increase in seeing, "there has been a definite improvement, and the seeing is more consistent." Thicksten noted, "The average seeing used to hover near 1.5 arcseconds, but we've seen it creep downward as we've made improvements. It's closer to an arcsecond now, and we're seeing a lot more subarcsecond nights."

— Tom Wilson

Messier Marathon Open to Northeasterners

This spring observers all over the northeastern United States will be pushing their observing skills to the limit when the North East Region of the Astronomical League (NERAL) holds a Messier Marathon for its members.

Each year astronomy groups hold Messier Marathons, contests of observing. Because of the distribution of Messier objects in the sky, early spring offers the chance to see all but one of the Messier objects in a single night. (Unfortunately

ASTRONOMY AstroCalendar

February 18-21
IAPPP Symposium: New Generation Small Telescopes, Lazy K Bar Ranch, Tucson, Arizona. Contact: Russell M. Genet, Fairborne Observatory, 1357 North 91st Place, Mesa, AZ 85207. Phone: (602) 986-2828, (602) 297-0702 for reservations.

February 18-21
4th Annual Winter Star Party (sponsored by the Southern Cross Astronomical Society), Florida Keys, Florida. Contact: Tippy D'Auria, 1051 N.W. 145th Street, Miami, FL 33168. Phone: (305) 685-6001.

April 23
15th Annual Astronomy Day. Contact: Gary E. Tomlinson, Chaffee Planetarium, 54 Jefferson Avenue SE, Grand Rapids, MI 49503. Phone: (616) 456-3985.

May 9-15
Texas Star Party, Prude Ranch, Fort Davis, Texas. Contact: TSP Registrar, 6433 Cedar Hollow, Dallas, TX 75248.

May 14
14th Annual Virginia Association of Astronomical Societies Convention (sponsored by the Back Bay Amateur Astronomers), South Hampton Roads, Virginia. Contact: Glen Howell, 2808 Flag Road, Chesapeake, VA 23323.

May 14
North Central Region of the Astronomical League Annual Convention (hosted by the Marquette Astronomical Society), Northern Michigan University, Marquette, Michigan. Contact: Jeanne Shibley, Registrar, 412 High Street #1, Marquette, MI. Phone: (906) 225-1066.

May 27-30
Riverside Telescope Makers Conference, Camp Oakes, Big Bear, California. Contact: Cliff Holmes, 8642 Wells Avenue, Riverside, CA 92503. Phone: (714) 689-6893.

June 25-26
The Universe in the Classroom (weekend credit workshop on teaching astronomy in grades 3-12 for U.S. and Canadian teachers, sponsored by the Astronomical Society of the Pacific and the Royal Astronomical Society of Canada), University of Victoria, Victoria, British Columbia, Canada. Contact: Teachers Workshop, A.S.P., 1290 24th Avenue, San Francisco, CA 94122.

June 25-July 2
100th Annual Meeting of the Astronomical Society of the Pacific, jointly sponsored by the Royal Astronomical Society of Canada and the Western Amateur Astronomers, University of Victoria, Victoria, British Columbia, Canada. Contact: A.S.P., Summer Meeting Department, 1290 24th Avenue, San Francisco, CA 94122.

AstroCalendar notices must be submitted at least four months in advance of the date of the event.

When contacting organizations that are sponsoring events, enclose a self-addressed, stamped, legal-size envelope for their response.

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Mark Davenport, Pinellas Park, Fla.

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M30, a globular cluster in Capricornus, lies too close to the Sun to be visible.)

The purpose of the marathon is to observe as many of the 107 Messier objects as possible in one night and document the observations. Observers must find the objects without the aid of setting circles, computers, or other technological devices. Contestants should submit a written checklist of objects observed that is signed by a club officer as witness.

The competition is open to all members of astronomical societies belonging to NERAL, and observations made between February 10 and April 10, 1988, can be used as entries. The winning observer, the one with the most objects observed, will receive a subscription to *Deep Sky* magazine. The astronomy club with the most total observations among its members will receive an inscribed plaque. For more information on the Messier Marathon program, contact Phil Harrington, 54A Dillmont Drive, Smithtown, NY 11787.

New Telescope Discovers Extragalactic Molecule

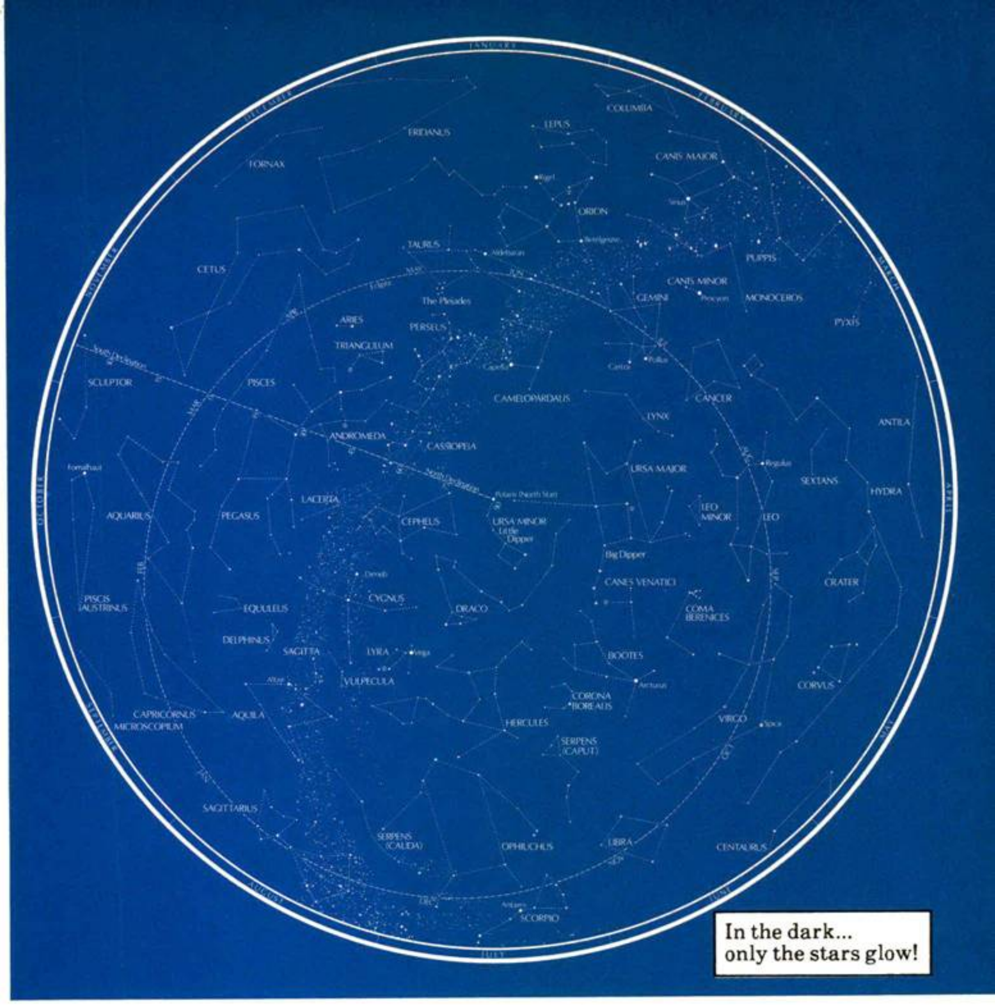
Discovery of the most complex organic molecule yet observed outside our Galaxy has been made by a new radio telescope that can detect wavelengths of a few millimeters, the region of the spectrum between radio and infrared.

A team led by Christian Henkel of the Max Planck Institute for Radio Astronomy in Bonn discovered the 3-millimeter signal of methanol (CH_3OH) coming from the galaxies IC 343 and NGC 253, both about 10 million light-years away. Many molecules in interstellar gas clouds emit radiation at wavelengths of 10 millimeters or less, which millimeter-wave telescopes can detect.

Millimeter-wave astronomy has taken off in recent years and has opened new areas of research in the physics and chemistry of interstellar gas and dust in our Galaxy. This area of research has been especially important in probing star-forming gas clouds to determine such physical properties as the cloud's molecular and atomic abundances, density, and temperature.

The discovery inaugurates a new 30-meter radio telescope devoted to millimeter-wave studies. The telescope is operated by the Institute for Millimeter Radio Astronomy and was set up by the Max Planck Institute in Germany and the French National Centre for Scientific Research. Second in size only to the 45-meter dish in Japan, the Franco-German telescope has a more accurate surface than the Japanese instrument and works at shorter wavelengths, down to 1 millimeter or less. Telescope operations began on September 14, 1987, on the 2,850-meter peak Pico Veleta in southern Spain near Granada.

— Ian Ridpath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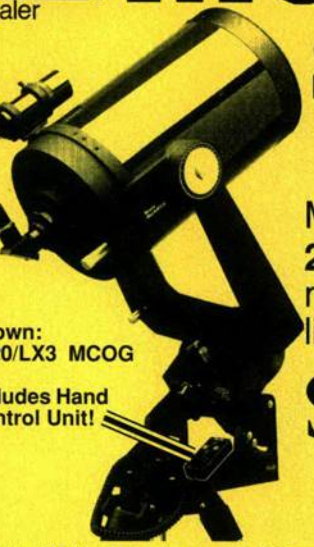

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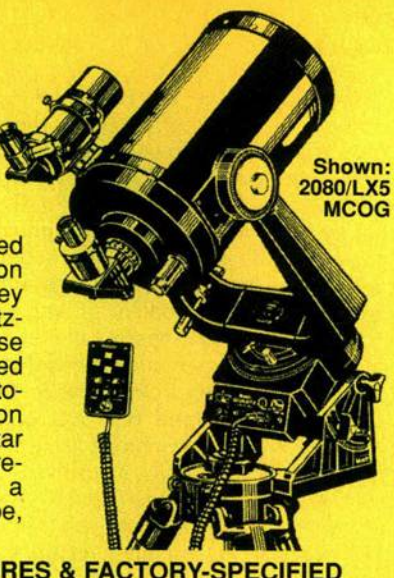

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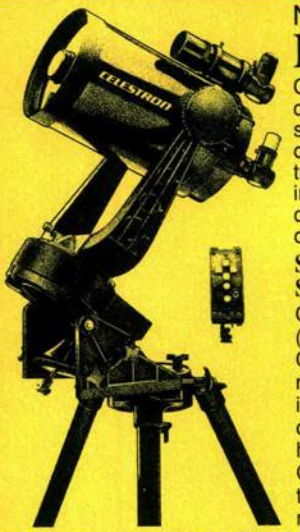

Celestron's newest incarnation of their classic fork-mounted Schmidt-Cassegrain is so advanced that it is *ONLY* offered with built-in QUARTZ microelectronic drive corrector (hand control unit included!) and STARBRIGHT optical coatings. AC or DC, N or S hemisphere operation, its ready-to-go!

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Complete f/10 telescope tube assembly (8" aperture, 2000mm focal length), with Celestron's world-famous, hand corrected, diffraction-limited, laser tested, individually certified ("Gold Standard") optical system; "STARBRIGHT" enhanced mirror coatings and "SPECIAL COATINGS" (anti-reflection coatings) on the corrector plate; widefield 8x50mm right-angle finderscope with built-in illuminated polar-alignment reticle; 1.25" visual accessory holder; high-brightness, enhanced-coatings mirror type 1.25" star diagonal; 26mm (77x), 1.25" barrel, multi-coated, premium-grade Plossl eyepiece; 7mm (285x), 1.25" barrel, fully coated, premium-grade, high-power Orthoscopic eyepiece; rugged dual-fork astronomical mount with graduated setting circles, manual positioning controls and clutches on both axes of motion; DIGITAL QUARTZ MICROELECTRONIC SIDEREAL-RATE PULSE-MOTOR DRIVE SYSTEM and ultra-precision 7.5" diameter "BYERS" worm-drive gearing built into telescope drive base; DRIVE CORRECTOR HAND CONTROL UNIT, with additional controls, and connectors for optional accessory electronic equipment (controls include "N/S" hemisphere switch, drive correction "rate" switch [2x or 4x the basic drive rate], N-E-S-W drive correction control buttons, drive rate adjustment knob [Lunar, Solar, Sidereal, etc.] for manual control of drive rate, red LED map-light, control switch for map-light, control switch and speed control knob for *optional* electric focus motor, connector for *optional* declination control motor, and coil-cord and plug for connection to telescope's drive base - note that the *optional* declination motor connects to either the hand control box or the telescope drive base, the *optional* focus motor connects only to the drive base); AC power adapter and cord/plug; DC battery-pack *(batteries not included)*; Deluxe Equatorial Wedge with micrometric adjusters for latitude and azimuth polar-alignment adjustments, latitude scale, bubble level and no-tool knob set; heavy-duty adjustable-height Field Tripod; dust covers for optical apertures; NEW EXTRA-RUGGED MOLDED CARRYING CASE FOR SCOPE-TUBE/FORK-MOUNT/DRIVE-BASE ASSEMBLY, WITH DIE-CUT FOAM LINING AND ROOM FOR ACCESSORIES; Instruction Manual; limited lifetime warranty.

PwrStr-C8 II ...... (List: $3,000) $1,679.95

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PIGGYBACK Bracket for camera, for C8 Tubes	(List: $ 50.00)	**$ 36.95**
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The HEAVYWEIGHTS!

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The SP-C8 is *still* your best dollar-value in a full-featured, significant-aperture, astronomical telescope. The complete kit includes *exactly the same* diffraction-limited 8" Schmidt-Cassegrain telescope tube assembly used on Celestron's much more expensive PwrStar C8 (shown at left), along with a high-quality German-type Equatorial Mount and adjustable Tripod that is loaded with standard features and capabilities, such as built-in *worm-gear* slow-motion controls on *both* axes of motion, setting circles and clutches on both axes, built-in micrometer azimuth and latitude adjusters, bubble level, and *built-in illuminated-reticle polar-alignment telescope!*

STANDARD FEATURES & FACTORY-SPECIFIED EQUIP

Complete f/10 telescope tube assembly (8" aperture, 2000mm focal length), with Celestron's world-famous, hand corrected, diffraction-limited, laser tested, individually certified ("Gold Standard") optical system; widefield 6x30mm straight-thru finderscope; 1.25" visual accessory holder; high-brightness, enhanced-coatings mirror type 1.25" star diagonal; 26mm (77x), 1.25" barrel, multi-coated, premium-grade Plossl eyepiece; piggyback camera bracket; hand strap for holding telescope tube assembly during setup and takedown; quick-mount slider bracket for mounting and balancing scope tube; German-type equatorial mount with: (1) full 360° worm-drive slow-motion/manual-positioning controls on both axes (with anti-backlash adjustments), (2) setting circles on both axes, (3) vernier brake/clutches on both axes, (4) micrometer latitude adjustment (0-90°!) with latitude scale, (5) micrometer azimuth adjustment, (6) bubble level, (7) built-in (in the polar axis shaft) illuminated-reticle polar alignment telescope, (8) sliding-type counterweight (for quick adjustment) on quick-disconnect counterweight shaft (for quick setup and takedown), and (9) vibration-damping adjustable wooden tripod with accessory tray; foam-lined carrying case for telescope tube assembly; dust covers for optical apertures; instruction manual; limited lifetime warranty.

SP-C8 .... (List: $1,620) .... $ 949.95
SP-C8 StrBrt ...... (List: $1,800) $1,099.95

FREE FREIGHT! (UPS Ground) for the SP-C8's shown above

Accessories for SP-C8 Telescopes

8x50mm St-Thru/RtAngle Finder & Mounting Bracket	(List: $ 200.00)	$ 99.95
1-Axis DC MotorDrive/Corrector	(List: $ 220.00)	$149.95
2-Axis DC MotorDrive/Corrector	(List: $ 380.00)	$269.95
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Celestron's CompuStar C8

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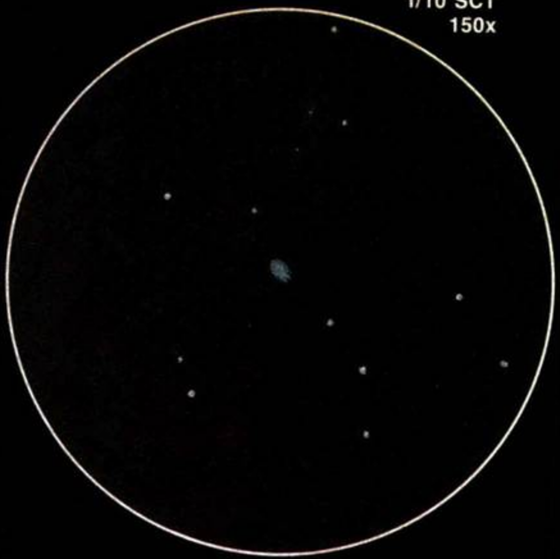
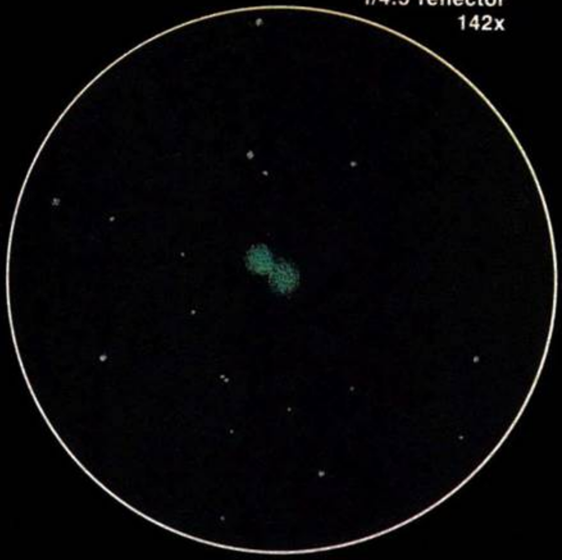
NGC 2022

8-inch
f/10 SCT
150x



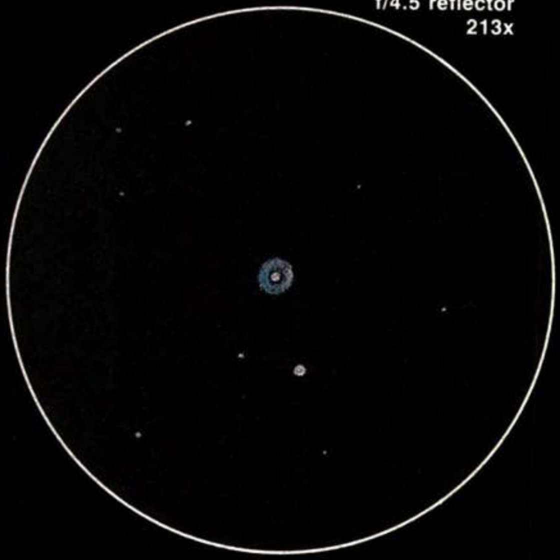
NGC 2371/2

17.5-inch
f/4.5 reflector
142x



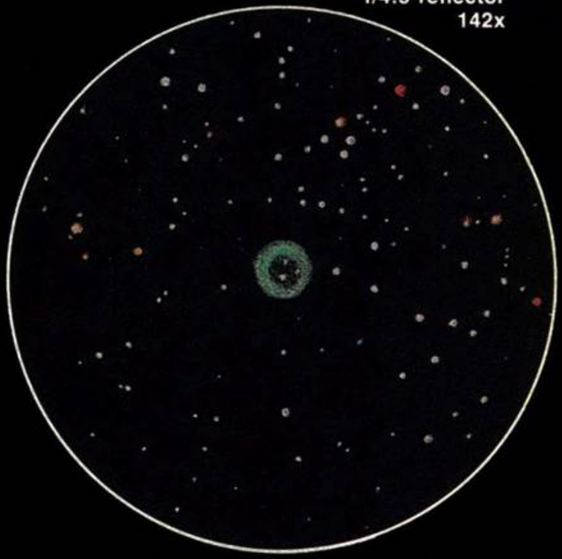
NGC 2392

17.5-inch
f/4.5 reflector
213x



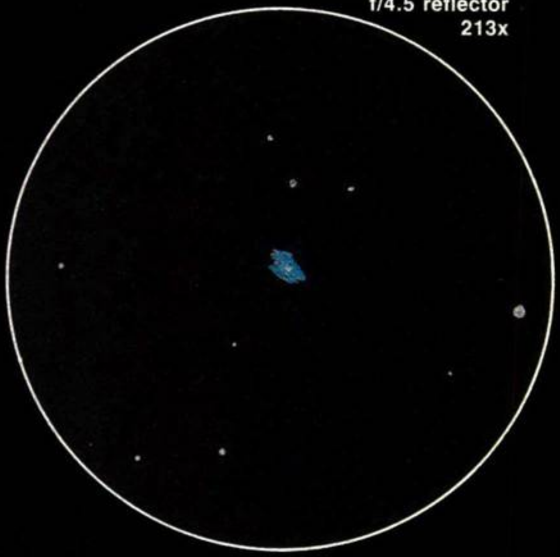
NGC 2438

17.5-inch
f/4.5 reflector
142x



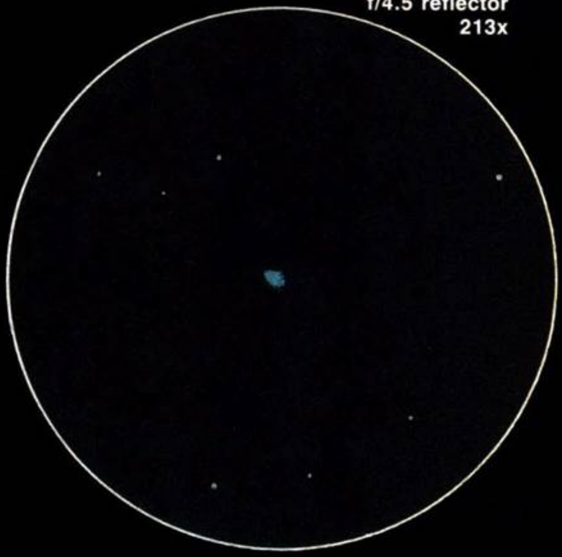
NGC 2440

17.5-inch
f/4.5 reflector
213x



IC 2149

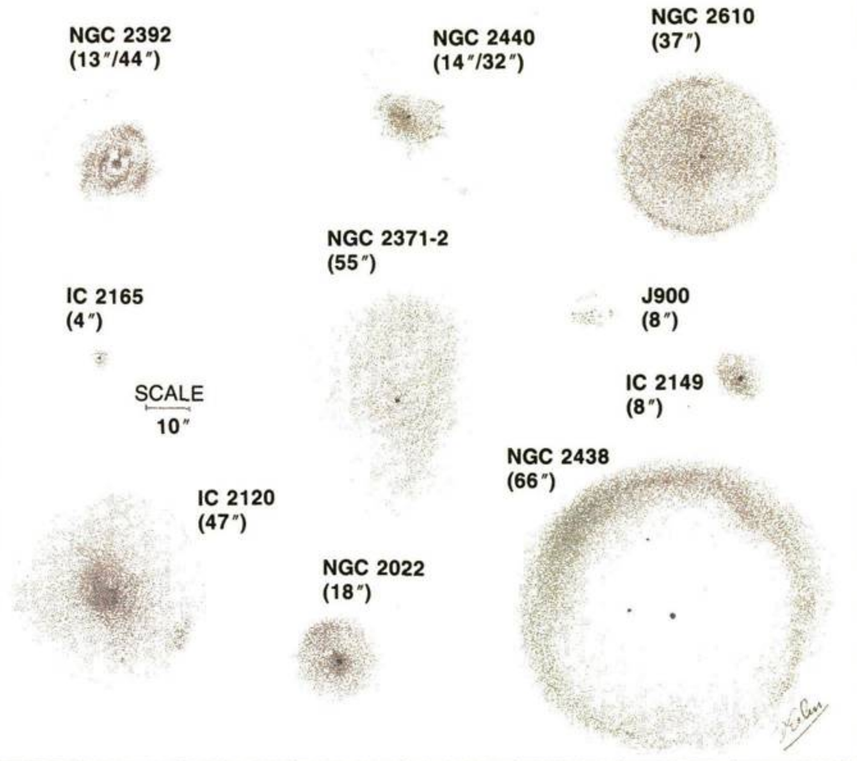
17.5-inch
f/4.5 reflector
213x



Sketches by David J. Eicher

Observing Planetaries in the Winter Hexagon

Relative Sizes of Planetary Nebulae in the Winter Hexagon



Sketches by David J. Eicher

I remember the first time I saw a planetary nebula. It was hard to believe that the small, circular disk of bluish light was really an enormous shell of faintly glowing gas puffed off by a dying star. You can see some fine examples of these remnants of stars past if you aim your telescope at the right spots along the winter Milky Way. Some of these planetaries appear like small, uniform disks in small telescopes (hence the name *planetary* nebula), while others are ring-shaped or show subtle detail that will test your observing skills on the best of nights. As an added challenge you can try to spot the central stars embedded in these shells of gas, the stars that created and light the nebulae by intense radiation.

Before you go hunting for planetaries, simply walk outside one clear night this March and look high in the sky. You'll see a giant, lazy circle of stars formed by the brightest members of Canis Major, Orion, Canis Minor, Gemini, Taurus, and Auriga. This circle of stars, called the Winter Hexagon, contains within its borders ten excellent examples of planetary nebulae.

One of the easiest planetaries to locate in the winter sky is **NGC 2438** in the southern constellation Puppis. Lying at the southeastern edge of the Hexagon, this bright, ring-shaped planetary nebula lies by chance directly in front of the star cluster M46. Therefore, to find NGC 2438, all you have to do is locate the star cluster. Start at Sirius and move your telescope 5° northeast to the bright star Gamma (γ) Canis Majoris. Next move your telescope 1° north and 9° east, and you'll see two hazy patches of light in your finder scope. The brighter of these is star cluster M47, and the fainter patch of light is M46.

With a low-power eyepiece the stars in M46 appear uniformly faint and nearly fill the field of view. Carefully scan the northern part of M46, and you'll see NGC 2438 as a faint circle of light that seems to float among the myriad stars. Center your telescope on NGC 2438 and insert an eyepiece that yields a magnification of 15x to 20x per inch of telescope aperture.

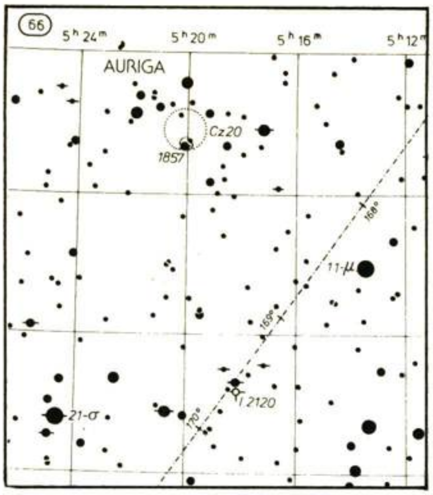
For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

If the seeing is good, you'll be rewarded by a crisp image of a well-defined ring slightly smaller and rounder than the famous Ring Nebula in Lyra. NGC 2438 is one of the best examples of a planetary nebula in the sky and is clearly visible as a ring in telescopes as small as 4 inches in aperture. NGC 2438 has a double structure: it shows a smooth disk of nebulosity that rises in brightness to a bright ring, the leading edge of the planetary's expanding shell of material. You may see three faint stars inside the ring shape of NGC 2438, but these are not associated with the nebula. NGC 2438's central star glows dimly at magnitude 17.7, well beyond the reach of amateur telescopes.

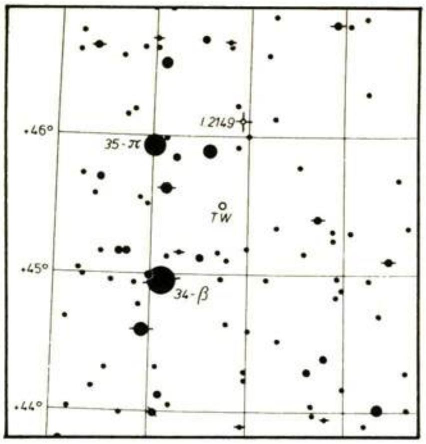
When you've finished viewing NGC 2438 and the surrounding sea of stars, move your telescope just over 3° south and you'll come to another planetary, **NGC 2440**. This object lies in a less populated starfield, so you may have to use a moderate magnification to find and identify its nonstellar disk. NGC 2440 also shows two distinct components, the brightest is an irregularly shaped disk 14″ across. Extending outward to a diameter of 32″ are two low surface brightness lobes of nebulosity. These extensions are so faint they are challenging for observers with the largest backyard telescopes. The 14th-magnitude central star is visible in a 12-inch telescope under extremely good seeing but is difficult to see on average nights because of the surrounding nebulosity.

Eight degrees east-southeast of the M46-M47 pair lies a flattened triangle of 5th- and 6th-magnitude stars including 20 and 21 Puppis. Some 4.5° east of the center of this triangle and just south of a 7th-magnitude star lies a little-known planetary nebula. Hydra's **NGC 2610** is a 37″-diameter planetary that has a photographic magnitude of 9.3 and appears as a smooth, pale disk of blue-gray light. Devoid of detail and nearly circular, NGC 2610 is a typical symmetrical disk planetary. Its magnitude 12.9 central star is visible in backyard telescopes only on nights of exceptional seeing.

On the other side of Sirius is a planetary nebula that will test your abilities as a keen-eyed observer. **IC 2165**, located 6.5° northwest of Sirius and in the same low-power field as a 6th-magnitude double star, measures a mere 4″ across. Because the nebula's photographic magnitude is 12.9, you'll need to use at least a 6-inch telescope to see IC 2165. Your best bet in spotting this challenging object is to locate the double star, move your telescope's field of view about 45′ to the east, and insert a high-power eyepiece.



The faint planetary IC 2120 in Auriga lies 5′ south of an 8th-magnitude double star, visible in this reproduction from *Uranometria 2000.0*. Copyright 1987 Willmann-Bell, Inc.



Although it lies just over 1° away from the bright star Beta Aurigae, IC 2149 is a challenge to find because of its small size. This section of *Uranometria 2000.0* shows the planetary midway between two 9th-magnitude stars. Copyright 1987 Willmann-Bell, Inc.

Carefully check the field of view with direct and averted vision, and if you don't see a slightly fuzzy star, sweep the telescope a slight amount until you do see one. IC 2165 will appear as a nebulous smudge without a central star.

Orion's lone bright planetary nebula is almost as easy to find as the ring nebula in open cluster M46. The familiar northern part of the constellation Orion consists of Betelgeuse, Saiph (Gamma [γ] Orionis), and a clump of stars designated Lambda (λ), Psi¹ (ψ¹), and Psi² (ψ²) Orionis. **NGC 2022** lies 3.5° northwest of Betelgeuse and 1° southeast of Psi² Orionis. This object is rather small, spanning 18″, but bright enough to be easily recognizable as a blue-green nebula at medium magnifications. NGC 2022 shows a hint of ring structure around its edges, but this detail is very difficult to observe visually. The nebula's central star glows at magnitude 15.2 and is also quite a challenge in backyard telescopes.

Way up in Auriga at the top of the Winter Hexagon lie two contrasting planetary nebulae. **IC 2120** is a relatively large planetary located 8° south of Capella and 1° west of Sigma (σ) Aurigae. A smooth disk with a moderately brighter portion toward the center, IC 2120 measures 47″ across and has a magnitude 15.1 central star that may just be visible under the best possible sky conditions. Auriga's other planetary, **IC 2149**, has a bright central star visible in almost any telescope but measures only 8″ across. Lying 1° north-northwest of Beta (β) Aurigae, IC 2149 is easy to find and appears as a uniformly illuminated disk of greenish nebulosity forming a perfect circle.

Gemini, with its twin bright stars Castor and Pollux that together form part of the Winter Hexagon, holds three splendid planetary nebulae for backyard observers. Three degrees northwest of Gamma Geminorum you can find the diminutive planetary **J900**. Faint at photographic magnitude 12.4, J900 measures 8″ across and appears similar to Auriga's IC 2149, although J900 has a much fainter central star that is difficult to spot in backyard telescopes. The shape of J900 is somewhat oval and its color a subtle gray-green.

On the other side of Gemini 3° southwest of Castor lies a patchy, irregular planetary nebula so confusing to astronomers of long ago that it received two NGC numbers. **NGC 2371-2** is a low surface brightness object requiring a dark sky to successfully observe, but it's also big. Spanning 55″, this nebula is easy to see on a dark night and appears as an oval blob of nebulosity with uneven illumination across its face. In the telescope NGC 2371-2 appears more like a galaxy than a planetary nebula, and its central star is too dim to easily see.

The most curious object in this part of the sky lies 2° east-southeast of the bright star Delta (δ) Geminorum. **NGC 2392** is a planetary so bright it is visible in any telescope. Although the brightest part of NGC 2392 spans a mere 13″, high power shows the bright blue color of this nebula quite impressively. Furthermore, NGC 2392 has a magnitude 10.5 central star visible in any instrument and an unusual fringe of mottled nebulosity that gave rise to the nicknames Eskimo Nebula and Clown Face Nebula.

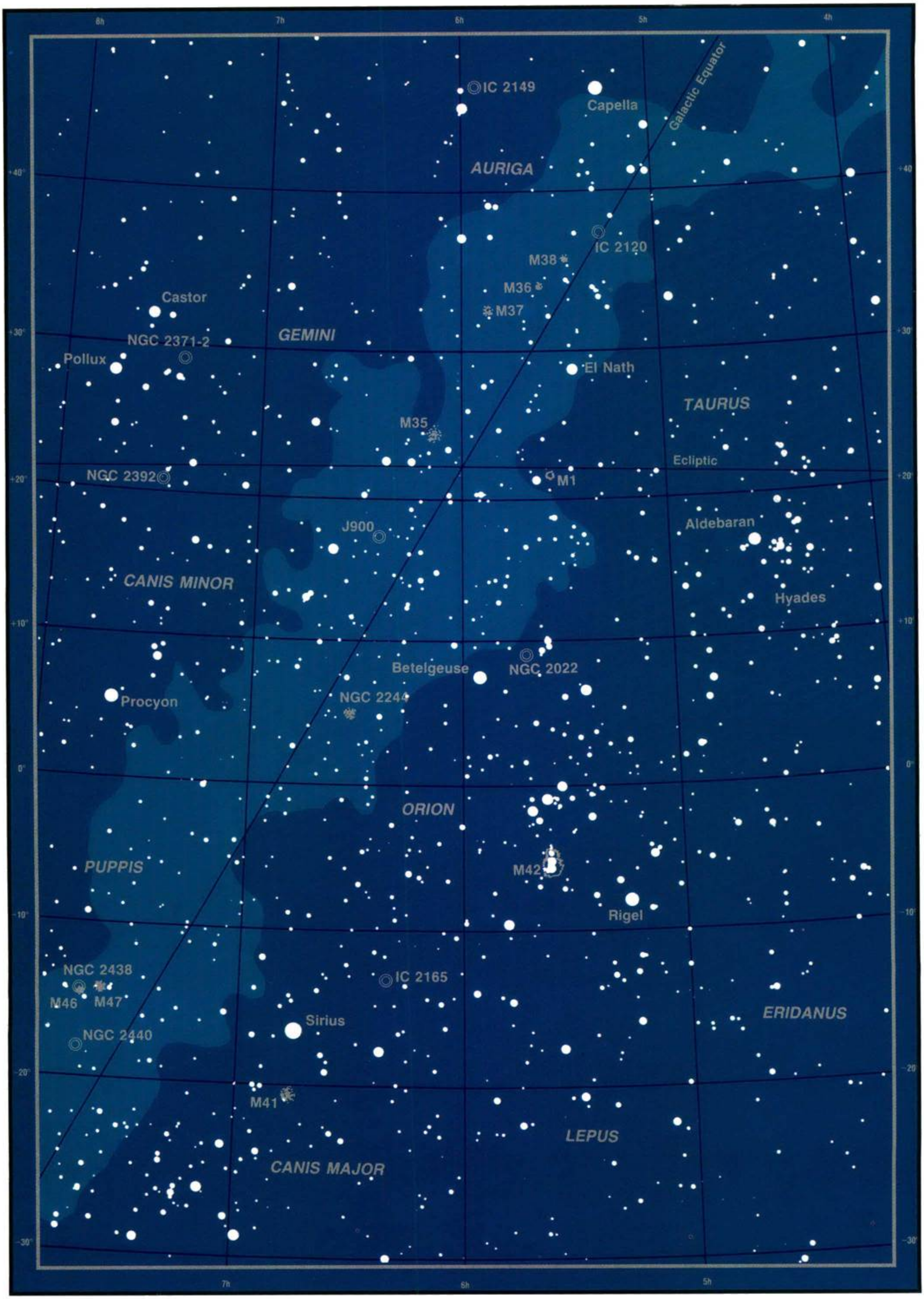
An extremely faint outer ring measuring 44″ across encircles the object, but the surface brightness of this ring is too low to permit spotting it with backyard scopes. The exciting possibility is that by using a large backyard telescope (one in the 12-inch to 20-inch range), you may be able to see some of the challenging detail on the face of NGC 2392. Wait for a particularly good night, use your best eyepieces, and experiment with averted vision and nebular filters if you have them. Study the features of the Eskimo Nebula carefully, and you just might on some late winter evening see a distant planetary nebula staring right back at you.

— David J. Eicher

Planetary Nebulae in the Winter Hexagon

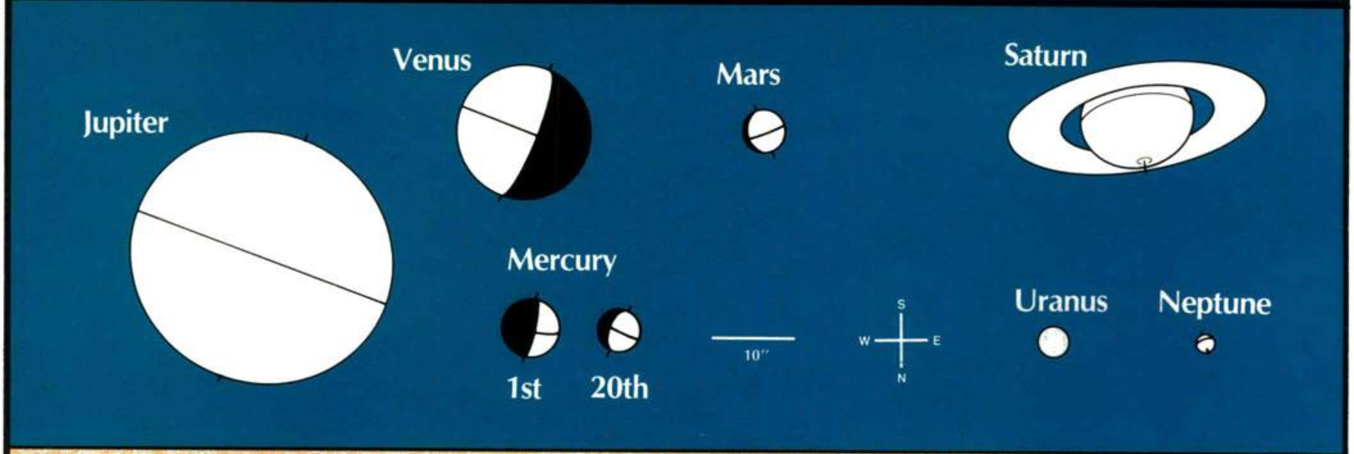
Object	Type	R.A. (2000)	Dec.	Con.	Mag.	Mag.★	Size	Dist.	Diam.
IC 2120	Smooth disk	5h 18.2m	+37°36′	Aur	—	15.1	47″	—	—
NGC 2022	Ring + smooth disk	5h 42.1m	+9°05′	Ori	12.4p	15.2	18″	2.1 kpc	0.2 pc
IC 2149	Smooth disk + irregular	5h 56.3m	+46°07′	Aur	11.2p	11.6	8″	1.0 kpc	0.04 pc
IC 2165	Irregular	6h 21.7m	−12°59′	CMa	12.9p	15.9	4″	3.1 kpc	0.06 pc
J900	Smooth disk + irregular	6h 25.9m	+17°47′	Gem	12.4p	16.3	8″	2.3 kpc	0.09 pc
NGC 2371-2	Irregular + ring	7h 25.6m	+29°29′	Gem	13.0p	15.5	55″	1.2 kpc	0.3 pc
NGC 2392	Irregular + ring	7h 29.2m	+20°55′	Gem	9.9p	10.5	13″/14″	0.9 kpc	0.2 pc
NGC 2438	Ring + smooth disk	7h 41.8m	−14°44′	Pup	10.1p	17.7:	66″	0.9 kpc	0.3 pc
NGC 2440	Ring + irregular	7h 41.9m	−18°13′	Pup	10.8p	14.3	14″/32″	1.1 kpc	0.2 pc
NGC 2610	Ring + smooth disk	8h 33.4m	−16°09′	Hya	9.3p	12.9	37″	1.1 kpc	0.2 pc

Object: Designation in NGC, IC, or other catalog. **Type:** Predominant observational features. **R.A. and Dec.:** Coordinates for epoch 2000.0. **Con.:** Constellation containing object. **Mag.:** Magnitude of nebula determined by photographic photometry; V magnitudes would be almost one magnitude brighter. **Mag.★:** Magnitude of central star (: indicates uncertainty about measurement). **Size:** Angular size in arcseconds. **Dist.:** Distance of nebula in kiloparsecs. **Diam.:** Linear diameter of nebula in parsecs.

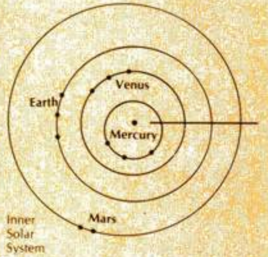

8h
7h
6h
5h
4h
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
IC 2149
Capella
Galactic Equator
AURIGA
IC 2120
M38
M36
M37
Castor
GEMINI
NGC 2371-2
Pollux
El Nath
TAURUS
M35
Ecliptic
NGC 2392
M1
J900
Aldebaran
CANIS MINOR
Hyades
Betelgeuse
NGC 2022
Procyon
NGC 2244
ORION
PUPPIS
M42
Rigel
NGC 2438
M46
M47
IC 2165
ERIDANUS
Sirius
NGC 2440
M41
LEPUS
CANIS MAJOR
7h
6h
5h

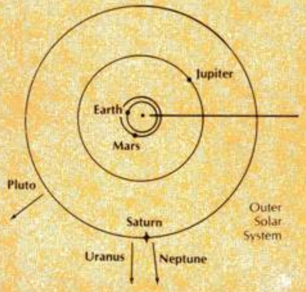
Planetary Data

March 1988


Jupiter
Venus
Mars
Saturn
Mercury
1st
20th
10″
S
W
E
N
Uranus
Neptune

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (2000.0)	Dec.
Sun		1	−26.8	32.3′	—	0.991	—	—	340°37.7′	22h 49.1m	−7°31.3′
		15	−26.8	32.2′	—	0.995	—	—	354°37.7′	23h 40.9m	−2°04.3′
		31	−26.7	32.0′	—	0.999	—	—	10°30.1′	0h 39.2m	−4°13.2′
Mercury	☿	1	0.4	8.1″	43%	0.828	0.439	216°21.7′	314°56.8′	21h 08.2m	−15°39.8′
		15	0.0	6.5″	66%	1.036	0.467	256°20.4′	328°21.6′	22h 04.2m	−13°27.0′
		31	−0.3	5.5″	83%	1.229	0.433	302°44.8′	351°48.0′	23h 33.4m	−5°27.4′
Venus	♀	1	−4.2	17.4″	67%	0.960	0.719	94°30.8′	24°00.6′	1h 27.8m	+10°02.9′
		15	−4.2	19.4″	61%	0.858	0.719	117°11.8′	39°36.3′	2h 26.6m	+16°27.7′
		31	−4.3	22.7″	53%	0.736	0.719	143°11.5′	56°27.0′	3h 33.6m	+22°19.6′
Mars	♂	10	1.0	6.0″	90%	1.566	1.516	243°38.1′	281°20.8′	18h 49.5m	−23°23.7′
		20	0.8	6.3″	89%	1.481	1.503	248°56.9′	288°06.0′	19h 18.8m	−22°50.4′
Jupiter	♃	15	−2.1	34.4″	100%	5.731	4.970	38°13.5′	31°31.7′	1h 58.8m	+11°03.7′
Saturn	♄	15	0.5	16.4″	100%	10.120	10.042	266°19.0′	272°06.0′	18h 09.2m	−22°17.8′
Uranus	⛢	15	5.7	3.6″	100%	19.345	19.262	267°55.1′	270°57.4′	18h 04.5m	−23°37.5′
Neptune	♆	15	8.0	2.2″	100%	30.475	30.227	278°10.1′	280°06.6′	18h 43.9m	−22°05.3′
Pluto	♇	15	13.7	0.1″	100%	29.018	29.669	220°51.2′	222°27.1′	15h 00.0m	+0°08.0′

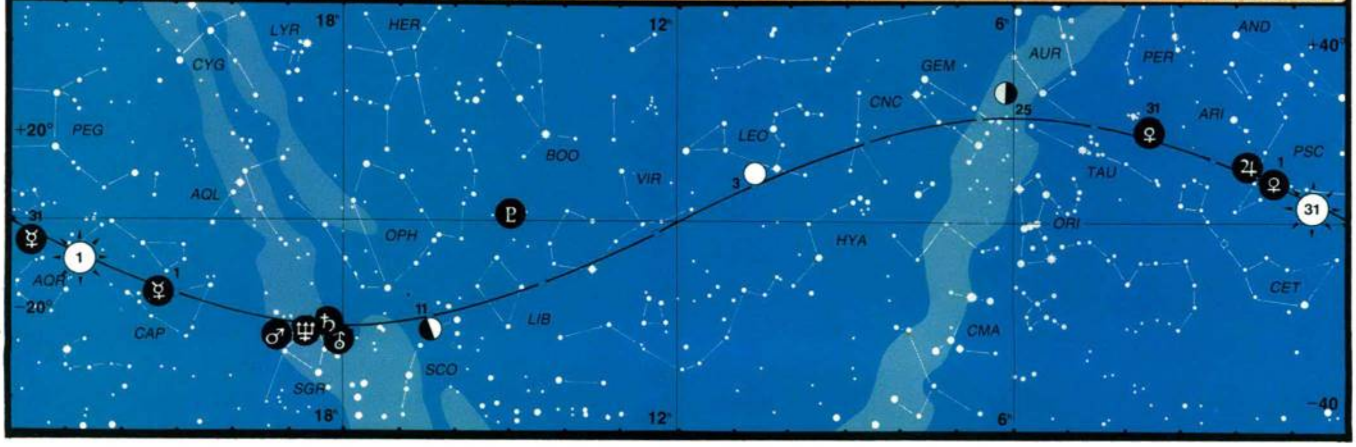

Venus
Earth
Mercury
Mars
Inner Solar System


Jupiter
Earth
Mars
Pluto
Saturn
Uranus
Neptune
Outer Solar System

Moon Data

Full Moon . . . . March 3 at 16h01m
Last Quarter . . . . March 11 at 10h56m
New Moon . . . . March 18 at 2h02m
First Quarter . . . . March 25 at 4h41m
Full Moon . . . . April 2 at 9h21m

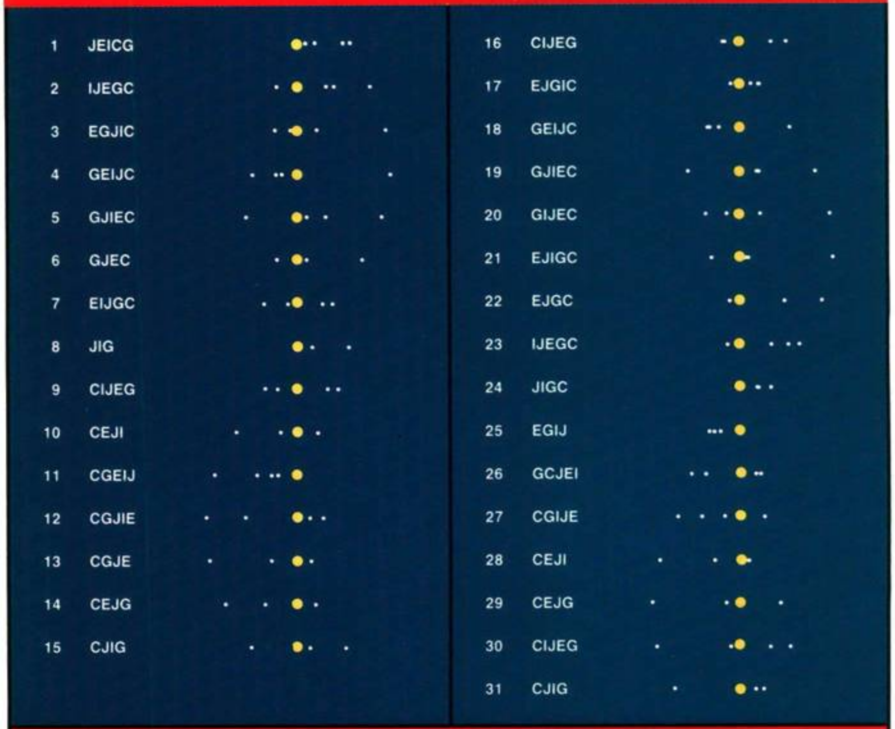
Apogee: March 1 at 11h52m . . . 406,251 km
Perigee: March 16 at 20h28m . . 359,517 km
Apogee: March 29 at 0h28m . . . 405,473 km


LYR
18h
HER
12h
6h
AUR
AND
+40°
CYG
GEM
PER
CNC
25
31
ARI
+20°
PEG
LEO
BOO
PSC
TAU
1
VIR
3
AQL
31
OPH
HYA
ORI
31
1
AQR
1
CET
−20°
CAP
LIB
11
CMA
SCO
SGR
18h
12h
6h
−40

Still visible in March but slowly sinking into the west, Orion's Great Nebula will be out of view in another few weeks. The splendid pink and blue hues visible in this photo are too subtle to see in a telescope, but you can observe the central cluster of stars enveloped in milky wisps of gray nebulosity. Photo by Randall R. Pfeiffer, who used a 14-inch SCT at f/6.4, hypersensitized SR 400 film, and a 25-minute exposure.

Satellites of Jupiter

2h00m UT


1 JEICG
2 IJEGC
3 EGJIC
4 GEIJC
5 GJIEC
6 GJEC
7 EIJGC
8 JIG
9 CIJEG
10 CEJI
11 CGEIJ
12 CGJIE
13 CGJE
14 CEJG
15 CJIG
16 CIJEG
17 EJGIC
18 GEIJC
19 GJIEC
20 GIJEC
21 EJIGC
22 EJGC
23 IJEGC
24 JIGC
25 EGIJ
26 GCJEI
27 CGIJE
28 CEJI
29 CEJG
30 CIJEG
31 CJIG

Jupiter = J, Io = I, Europa = E, Ganymede = G, Callisto = C
(South is at top, matching the view in a telescope)

Planets

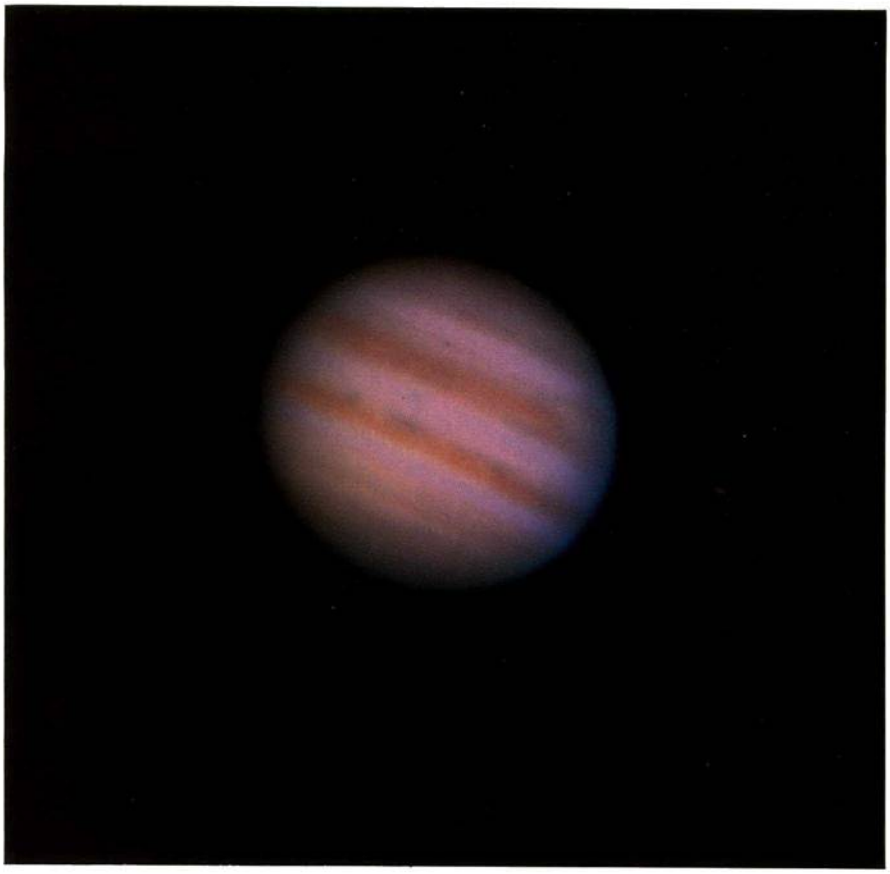
Mercury

Continuing the apparition that started last month, Mercury remains in view in the predawn sky during the first three weeks of March. Its elevation is highest on March 1 (4°, forty-five minutes before sunrise), but thereafter it slowly sinks until the planet vanishes around March 20. Greatest western elongation is on March 8, and superior conjunction follows on April 20.

A telescope shows Mercury's disk measuring 8.1″ across and about half-lit on the 1st. Over the following weeks Mercury becomes gibbous as it shrinks to a diameter of 6.1″ on the 20th. During this period Mercury brightens only slightly, from magnitudes 0.4 to 0.0.

Venus

Venus is always a brilliant jewel in any eyepiece, but this month its conjunction with Jupiter outshines everything else. At



Above: Throughout the last half of 1987 Jupiter showed a lot of atmospheric activity. This photo, made with a 30-inch f/4.5 telescope stopped-down to 10 inches in aperture, shows delicate, tawny bands striping the equatorial zones and subtle, cream-colored wisps of matter. Visible at right is the satellite Europa. Photo by Jack Zeiders, who used a 5-second exposure on Fujichrome 100 film at f/130.

20h25m UT on March 6, Venus lies only 2°24′ north of Jupiter, though the two planets are relatively close for a day or two before and after the 6th.

Shining boldly at magnitude −4.2, Venus is an impressive sight as it presents a white gibbous disk about 18″ across. Pastel-striped Jupiter is almost twice as large as Venus but two magnitudes dimmer. A 2-1/2° separation is too wide for all except the lowest power eyepieces on a rich-field telescope, but even if you can't include both Venus and Jupiter in the same field of view, scanning from one to the other will be an unforgettable experience.

Moon

At Full phase on March 3, the Moon slips through the northernmost edge of the Earth's shadow (the umbra) in a partial eclipse with an umbral phase lasting only 14 minutes. Mid-eclipse occurs at 16h13m UT and is visible just before moonset from Alaska and Hawaii. (The eclipse is more easily visible over the western Pacific, Asia, and eastern Europe.) Viewers with telescopes can see the dark umbra touch the extreme southern limb of the Moon, while regions farther away dim slightly as the penumbra slowly passes over them.

On March 17-18, a total solar eclipse occurs over Indonesia, the Philippines, and the northwestern Pacific Ocean. (The eclipse track crosses the International Data Line, hence the double date.) From North America the eclipse is visible only as a partial eclipse just before sunset for viewers in Alaska, the Yukon, and the westernmost islands of Hawaii.

Mars

The rapid eastward motion along the ecliptic this month keeps Mars at about the same elevation in the morning sky every day: 20°, forty-five minutes before sunrise. Mars, which grows 1″ during March (from 5.7″ to 6.7″), is now large enough to start a serious "Mars watch" for the coming opposition. (See the article on page 58.)

Minor Planets

1 Ceres (magnitude 8.9) is moving eastward out of Capricornus into Aquarius. Its positions:

1st: 21h51m15s, −20°11.8′
10th: 22h05m13s, −19°12.1′
20th: 22h20m23s, −18°05.4′
30th: 22h35m06s, −16°59.5′

Ceres rises around 5:30 a.m. local time on the 15th.

2 Pallas (10.4), moving eastward, passes 2°20′ south of Altair (Alpha [α] Aquilae) on March 2. Its positions:

1st: 19h49m00s, 6°26.0′
10th: 19h59m09s, 7°19.6′
20th: 20h09m40s, 8°24.4′
30th: 20h19m13s, 9°33.7′

Pallas rises around 2 a.m. local time at mid-month.

3 Juno (9.7) is moving eastward in north-central Cetus and eastern Pisces. It passes about 2°16′ north of Alrisha (Alpha [α] Piscium) on March 29. Juno's positions:

1st: 1h00m49s, −0°03.2′
10th: 1h19m47s, 1°34.8′
20th: 1h41m16s, 3°22.7′
30th: 2h03m11s, 5°07.8′

Juno sets about 8 p.m. local time on the 15th.

4 Vesta (7.4) is stationary in Gemini on March 10, about 1°50′ south of Pollux (Beta [β] Geminorum). Vesta is occulted by the Moon on March 26 at around 20h UT. Its positions:

1st: 7h47m01s, 26°01.4′
10th: 7h45m41s, 26°11.2′
20th: 7h47m03s, 26°11.5′
30th: 7h51m34s, 26°01.9′

Vesta sets around 4 a.m. local time on the 15th.

To locate a minor planet, photocopy the appropriate chart from a good star atlas (*Uranometria 2000.0*, for example), plot the object's dated positions lightly in pencil, and sketch a smooth curve linking the points. (Coordinates are in epoch 2000.0 for 0h UT.) Then observe the starfield at low magnification and photograph or plot by hand what you see. Recheck the field a night or two later; the "star" that moved is the minor planet.

Jupiter

During the weeks following conjunction with Venus (see above), Jupiter swiftly drops toward the horizon. By the end of March it is just 13° high, forty-five minutes after sunset — well under half its elevation on March 1. This is low enough to bring it down to the region of frequently poor seeing along the horizon. Therefore try to observe Jupiter as much as you can early in the month.

Saturn

Though it lies among the summer stars of Ophiuchus and Scorpius, Saturn stands high enough in the southeast during the predawn to make viewing it a pleasure. Measuring 16.4" across its equator, Saturn (minus rings) will resemble a faded cousin of Jupiter. Yet as morning twilight turns the sky around it blue, Saturn's ivory disk may briefly reveal a few additional details that escape your eye when you see it in a fully dark sky.

Uranus

Uranus spends all month within 2° of Saturn. For example, on the 15th, look for Uranus 1°20′ south and 1°10′ west of Saturn. Uranus has a distinctive blue-green disk that measures 3.6" across and glows at magnitude 5.7.

Neptune

Finding Neptune is easy this month as Mars passes 1°22′ south of Neptune at 21h47m UT on the 7th. Neptune has an 8th-magnitude gray disk, 2.2" in diameter.

Pluto

Pluto lies near the region where Virgo, Libra, and Serpens Caput join, which rises at around 8 or 9 p.m. and remains visible until sunrise. Yet spotting Pluto is difficult even for experienced observers. You will need a 10- to 12-inch telescope, the finder chart in the January issue, and lots of patience over several moonless nights.

Locate the correct area and then map what you see, either by hand or with photography. Next, recheck the same field a day or so later — the object that moved is Pluto. In March Pluto is a 13.7-magnitude dot of light moving west-northwest. Once you have located Pluto, remember its position by reobserving at every opportunity.

— *Robert Burnham*

Above: Michael Stecker's photo of Comet Bradfield 1987s nets this month's $100 "Best Astrophoto" award. Stecker used an 8-inch f/4 hyperbolic reflector and hypersensitized Konica SR 1600 film copied onto 5072 recording film.

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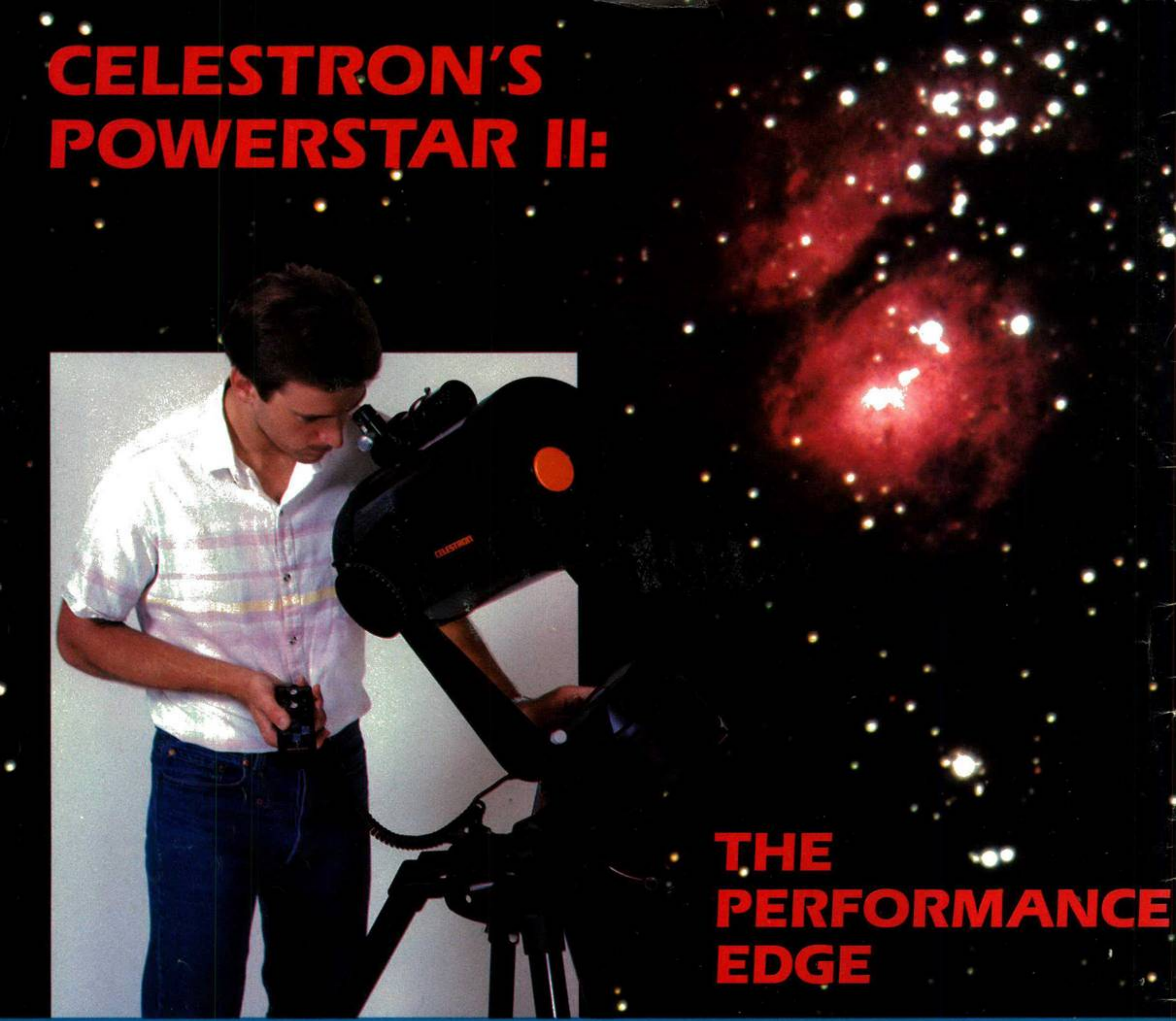

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